High accuracy synchrotron radiation interferometry with relativistic electrons

A1 Collaboration and friends

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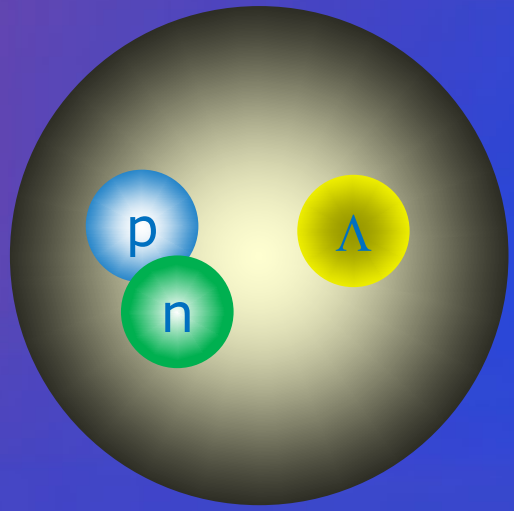
Energy measurement for spectrometer calibration

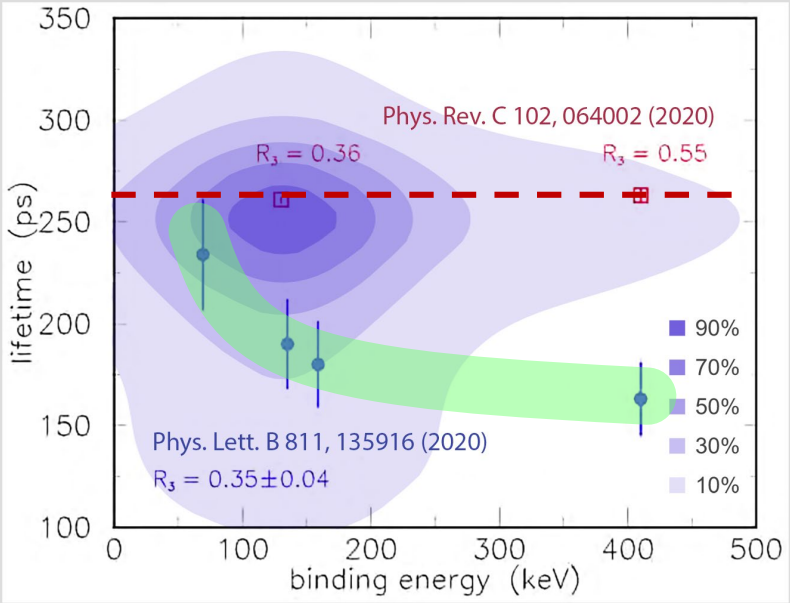
Do we understand the simplest Hypernucleus?

$^{3}_{\Lambda}\mathrm{H}$



Hypertriton – still a puzzle?

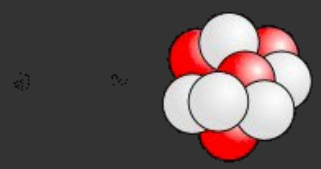
- Small BE of ${}^{3}_{\Lambda}$H and a lifetime significantly below $\tau(\Lambda)$ were puzzling
- Theoretical calculations incl. π FSI



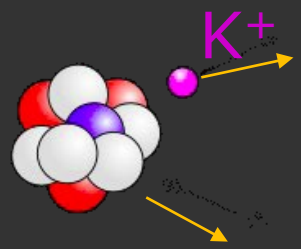
Approaching era of precision and accuracy by new experiments

- MAMI A1 2022: π spectroscopy: $\Delta B \sim \pm 10 \pm 30$ keV
- JLab E12-19-002: missing mass: $\Delta B \sim \pm 20 \pm 70$ keV; 1^+ state?
- ELPH: direct measurement of hypertriton lifetime (γ, K^+)
- J-PARC (π^-, K^0)
- HYPHI (FAIR Phase 0),ALICE, STAR

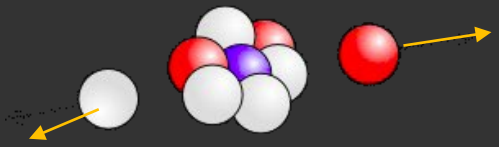
High resolution pion spectroscopy



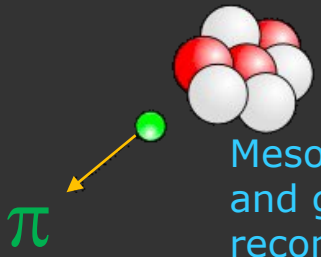
Electroproduction of excited hypernuclei on ^{9}Be Target



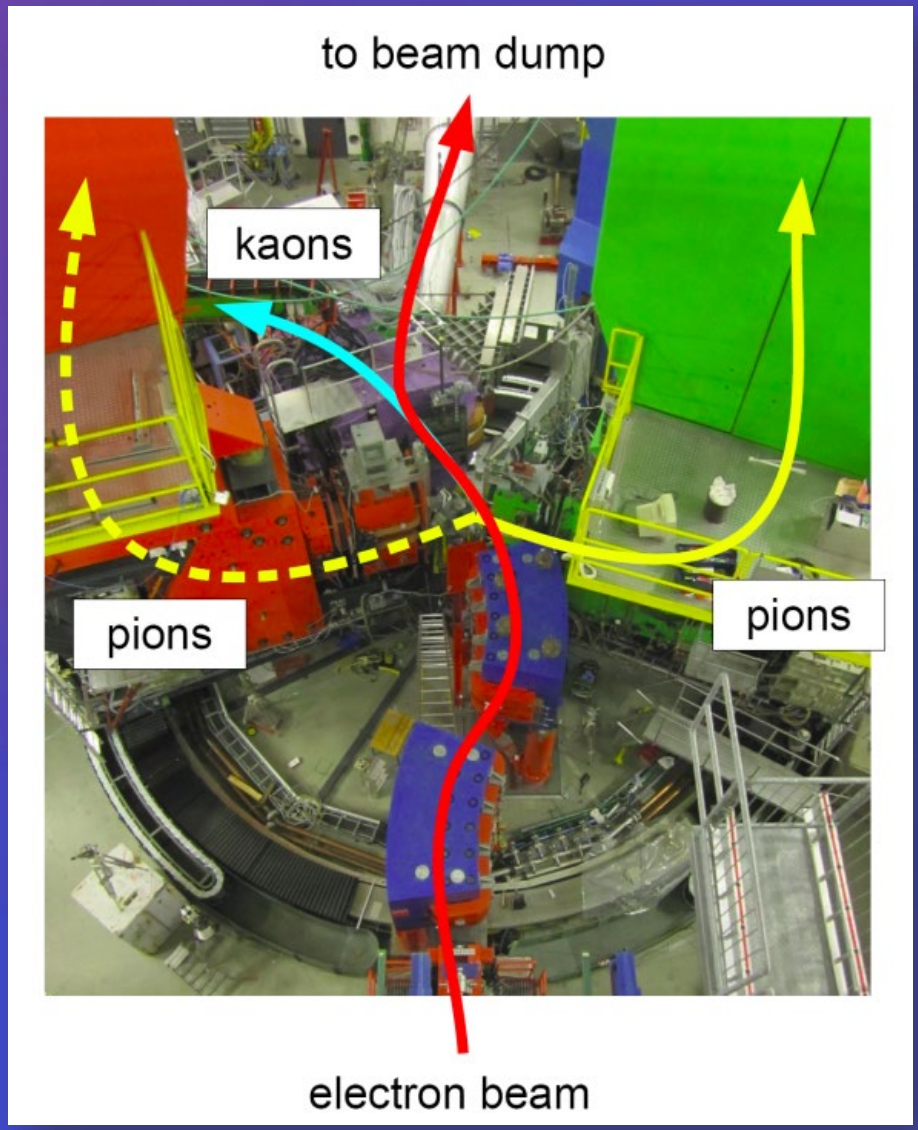
Event tagging by kaon detection



Fragmentation produces several light hypernuclei

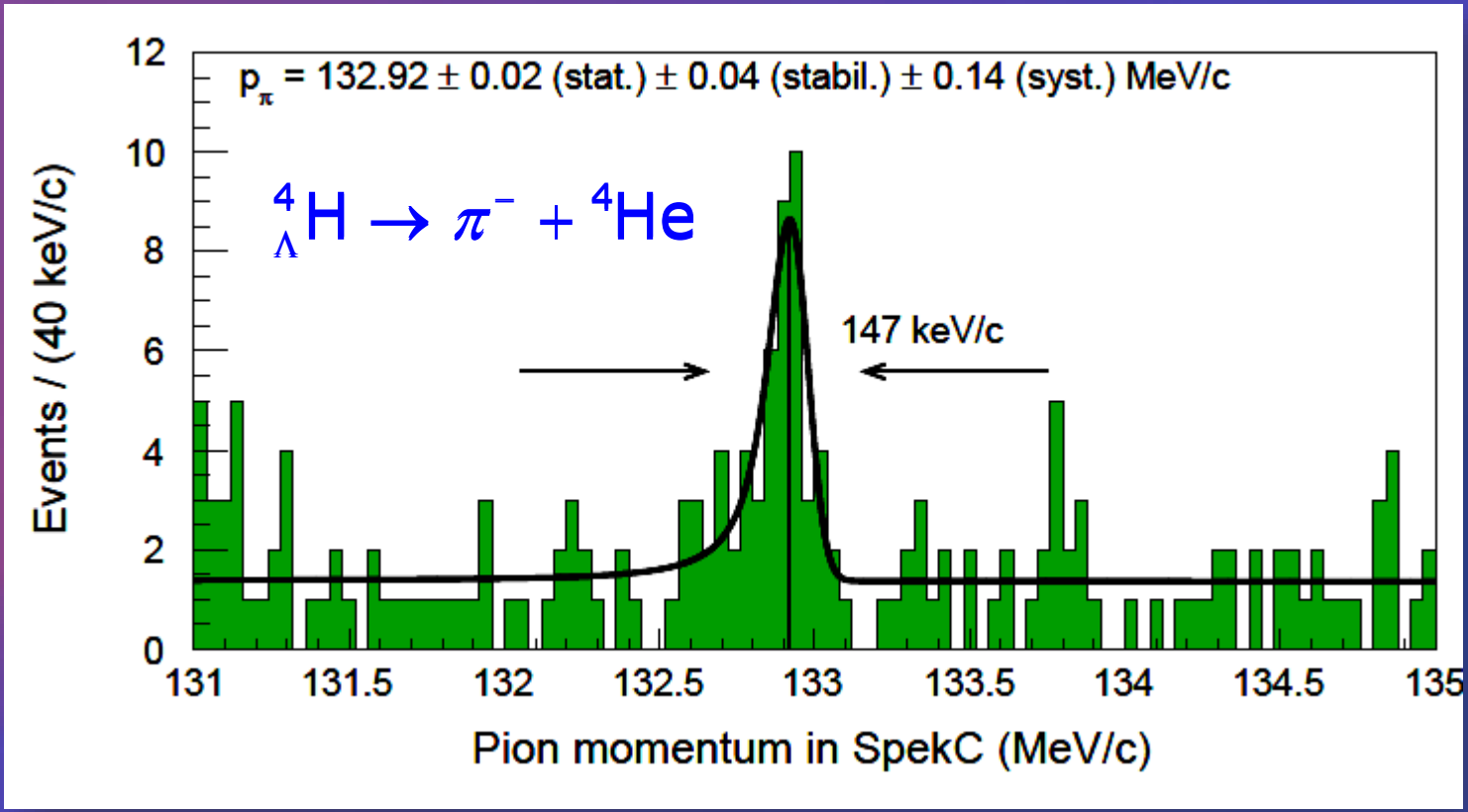


Mesonic weak decay and groundstate mass reconstruction by spectroscopy of pions from two-body decay



Phys. Rev. Lett. **115**, 222501 (2015)

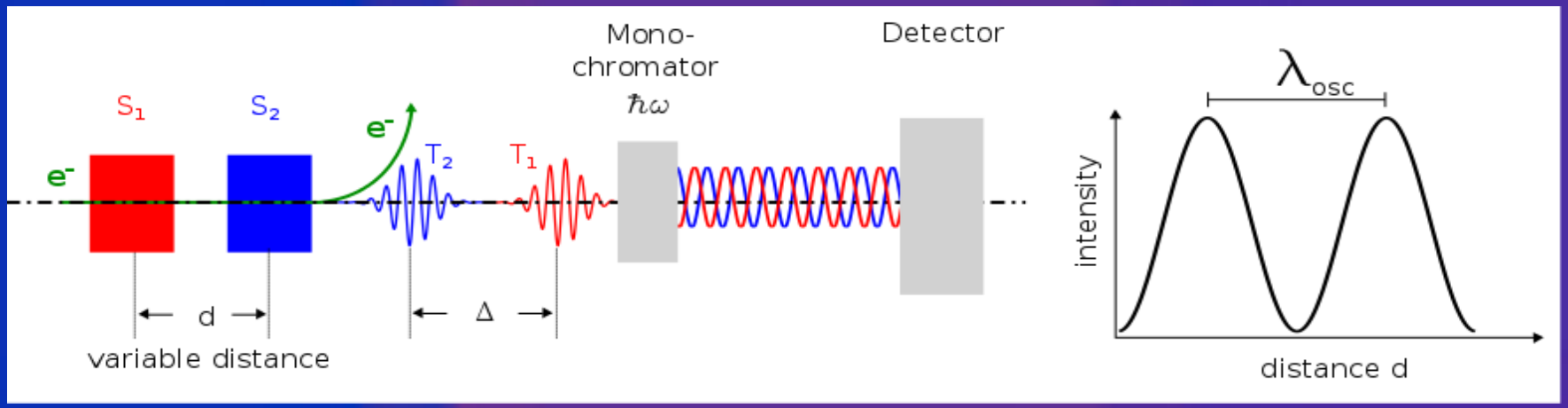
High resolution pion spectroscopy



- Main systematic error due to uncertainty of the absolute MAMI beam energy
  - improved luminosity with Li target
  - interference of coherent undulator radiation

Method

Undulators	Wave packets	Monochro-matic light	Light intensity of selected wavelength

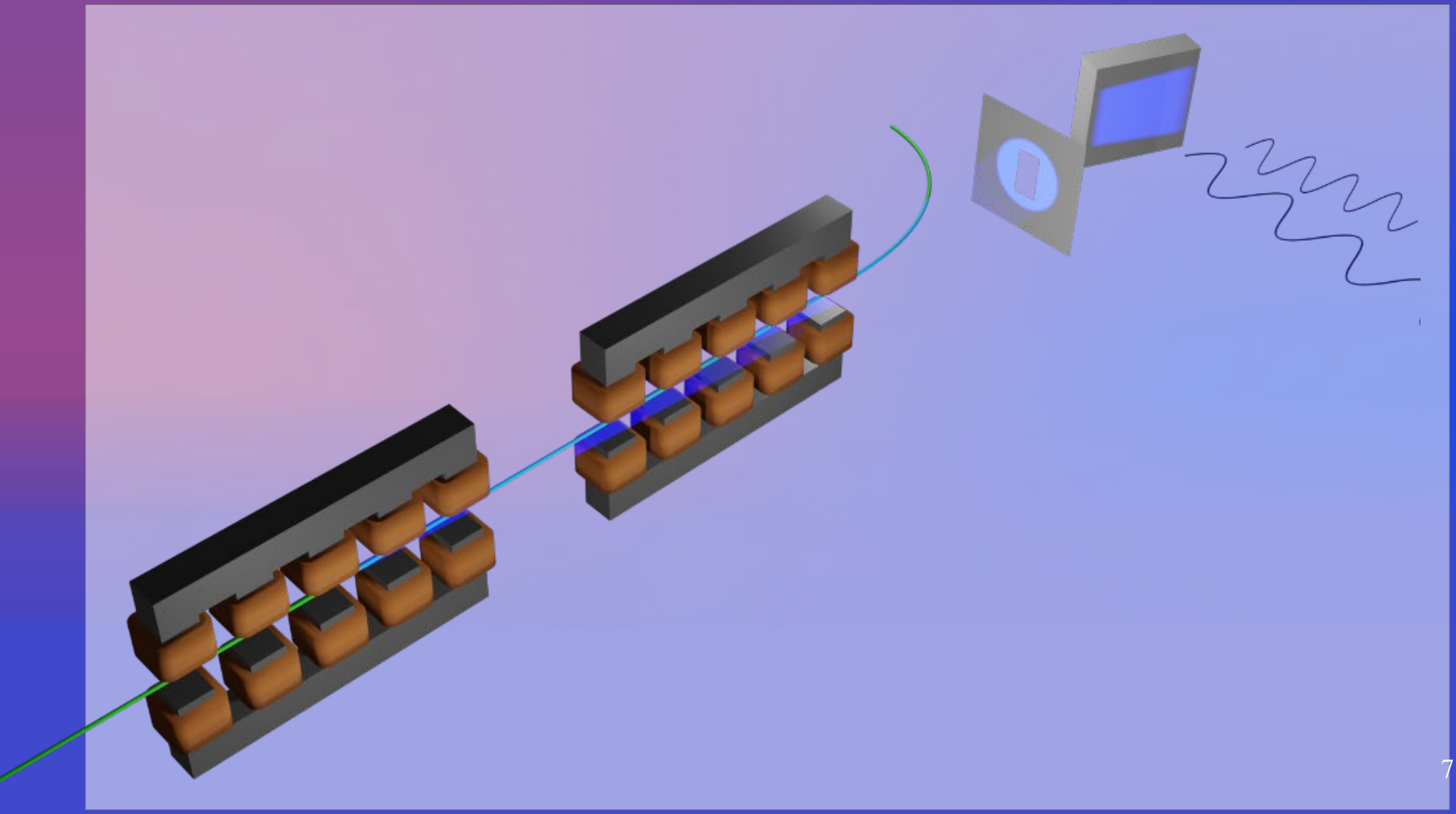


$$\lambda_{osc} = 2\gamma^2 \lambda_L$$

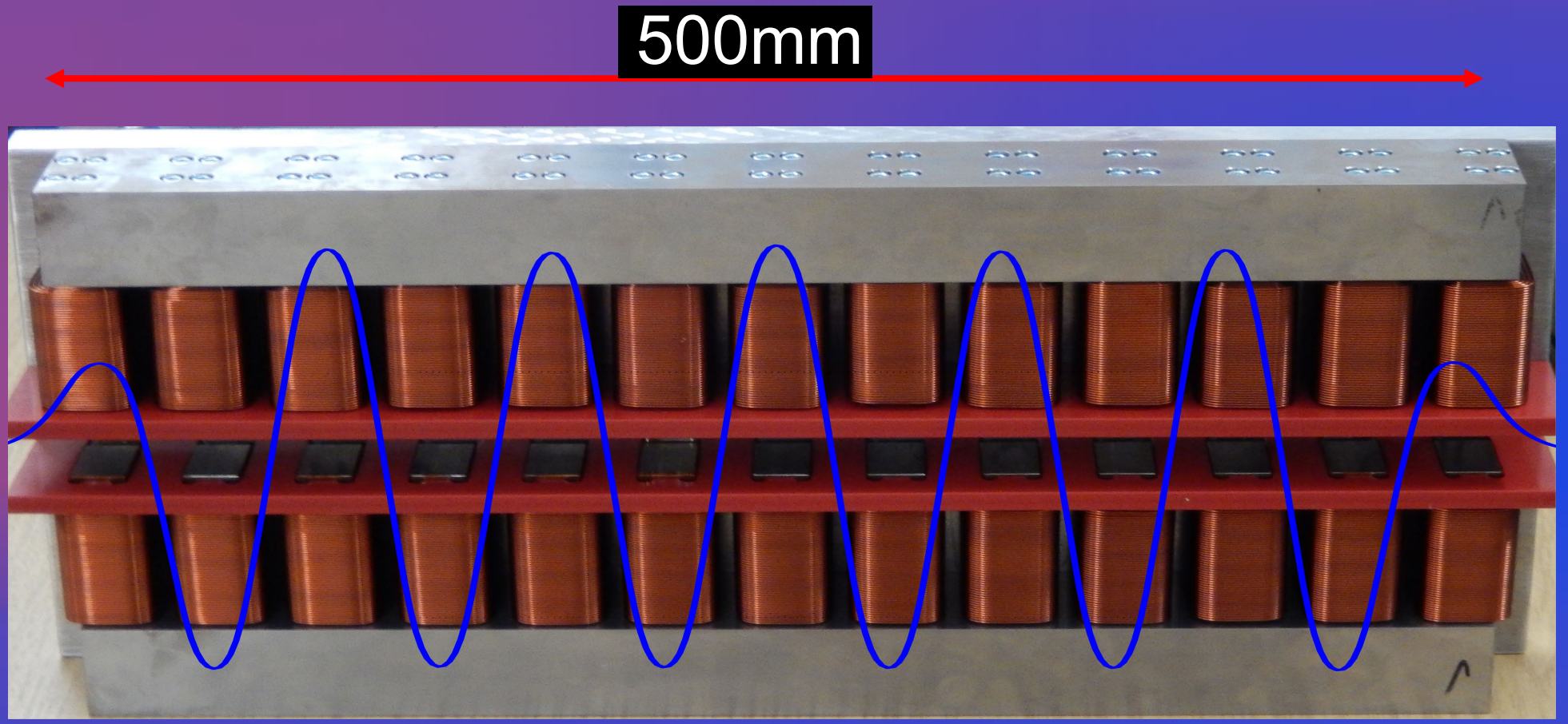
Example for wavelength and period

$$\left.\begin{array}{l} \lambda_L \approx 400\text{nm} \\ \gamma \approx 381, \text{E=195MeV} \end{array}\right\} \lambda_{osc} \approx 116\text{mm}$$

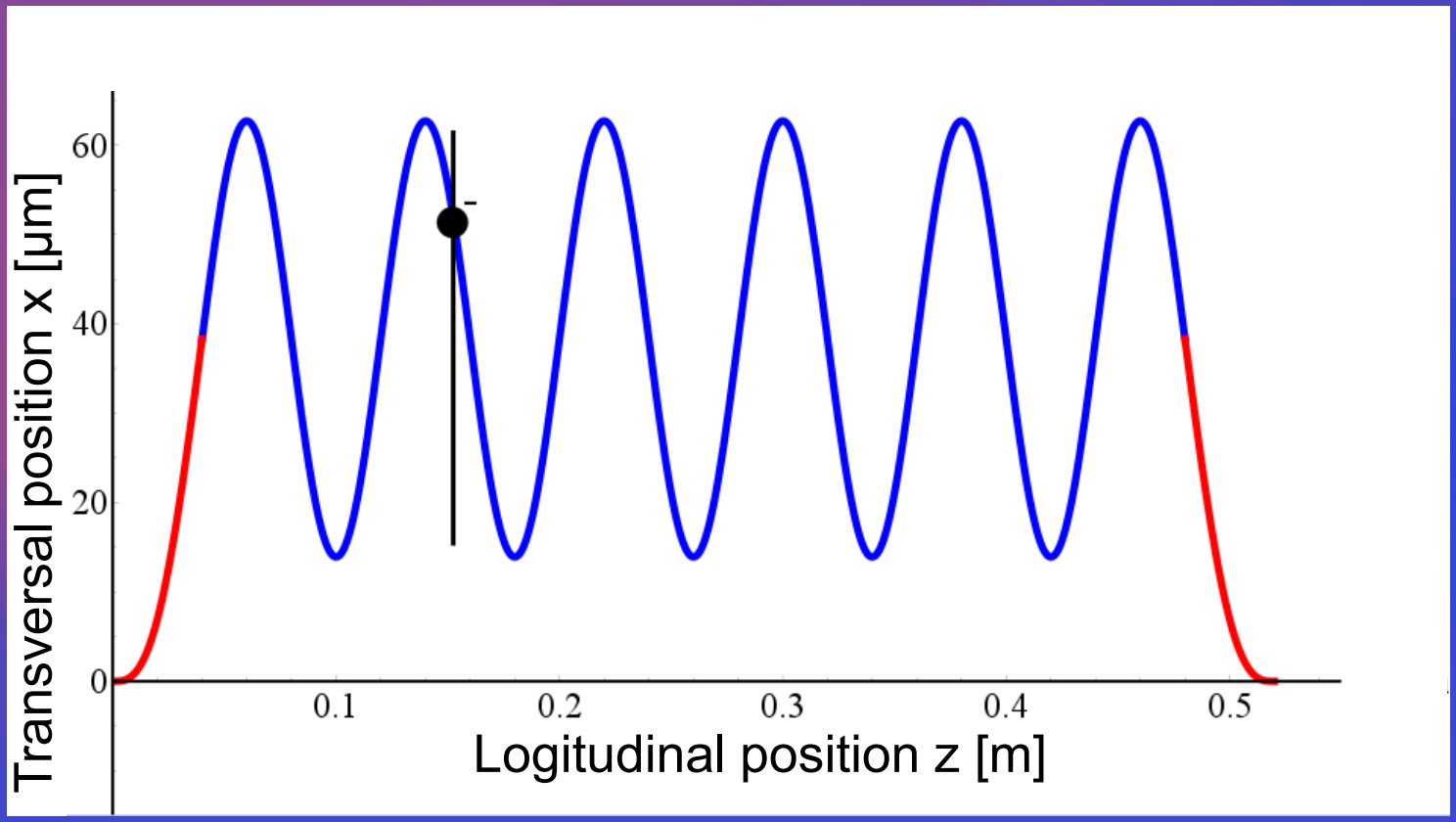
Undulator pair



Undulator magnetic field

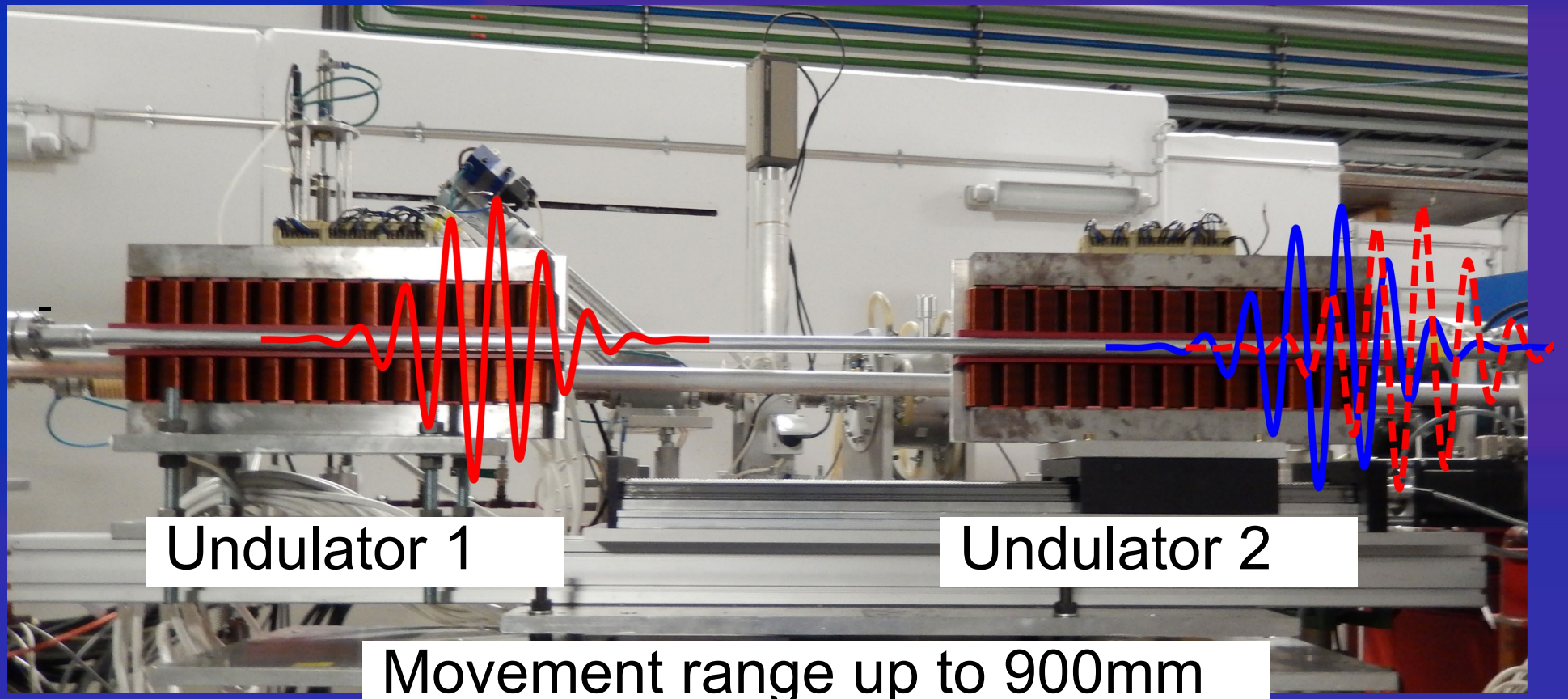


Emission of synchrotron radiation

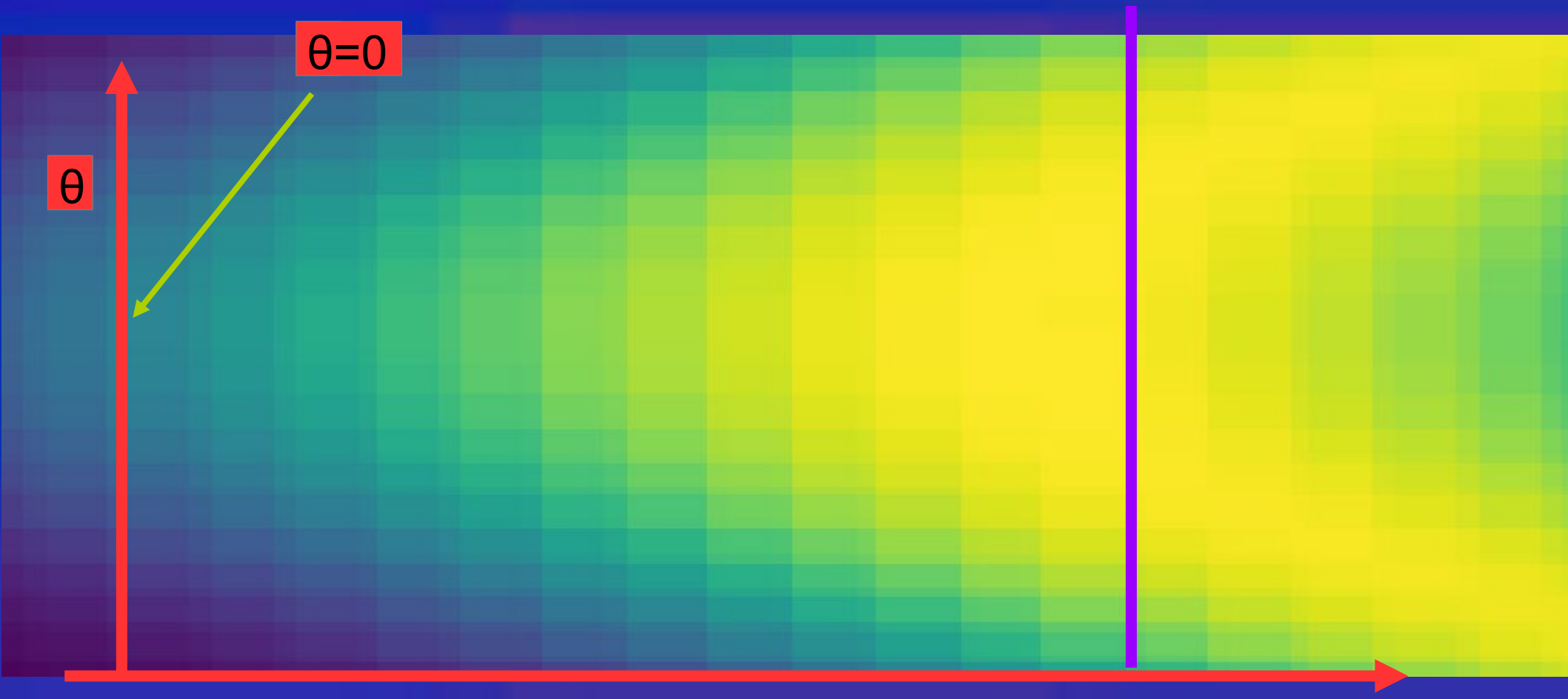


- Electrons oscillate perpendicular to the z-Axis
- The black bar suggests the idea of a high relativistic antenna moving towards the observer
- Emission takes place only in a finite length

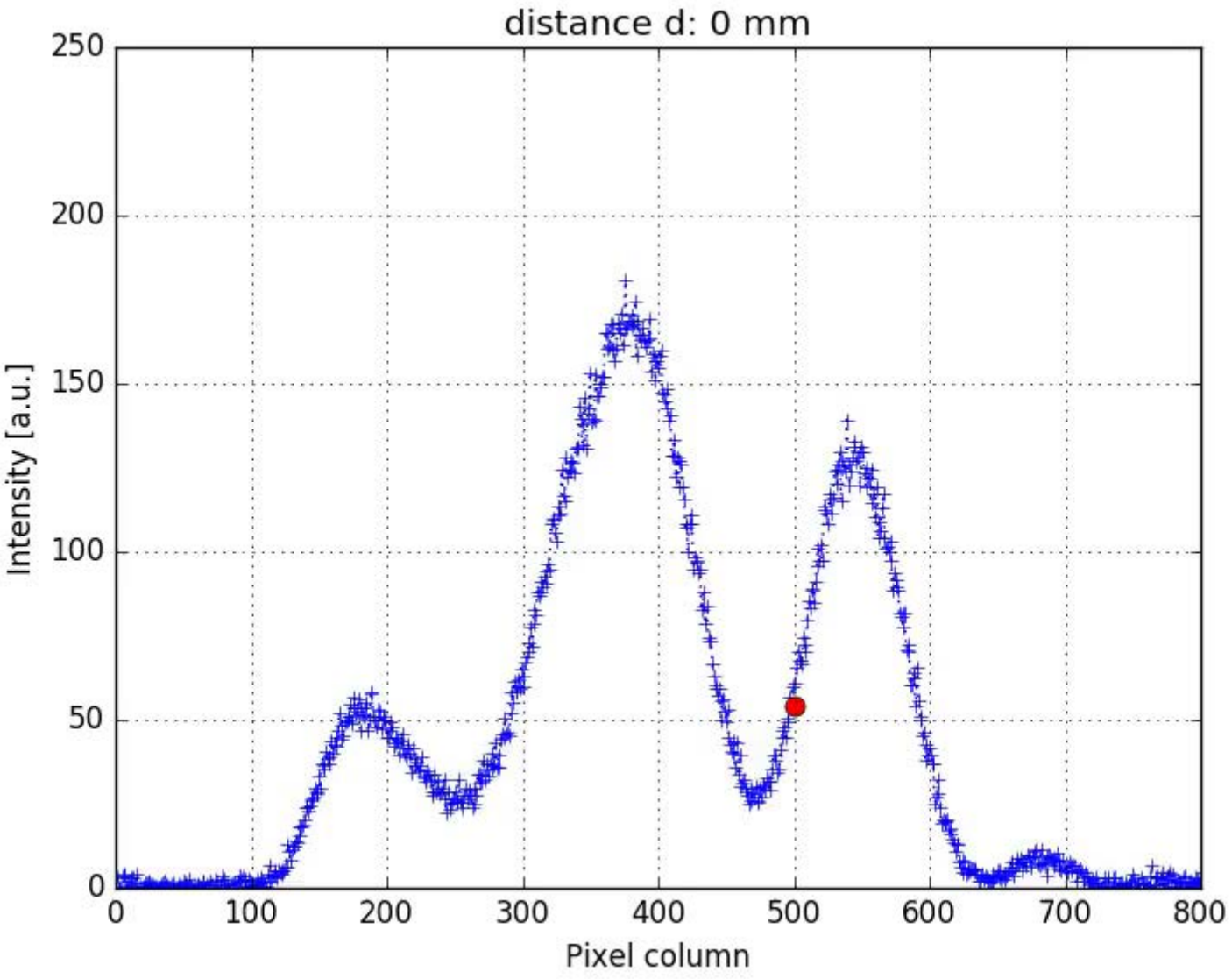
Two undulators acting as light sources



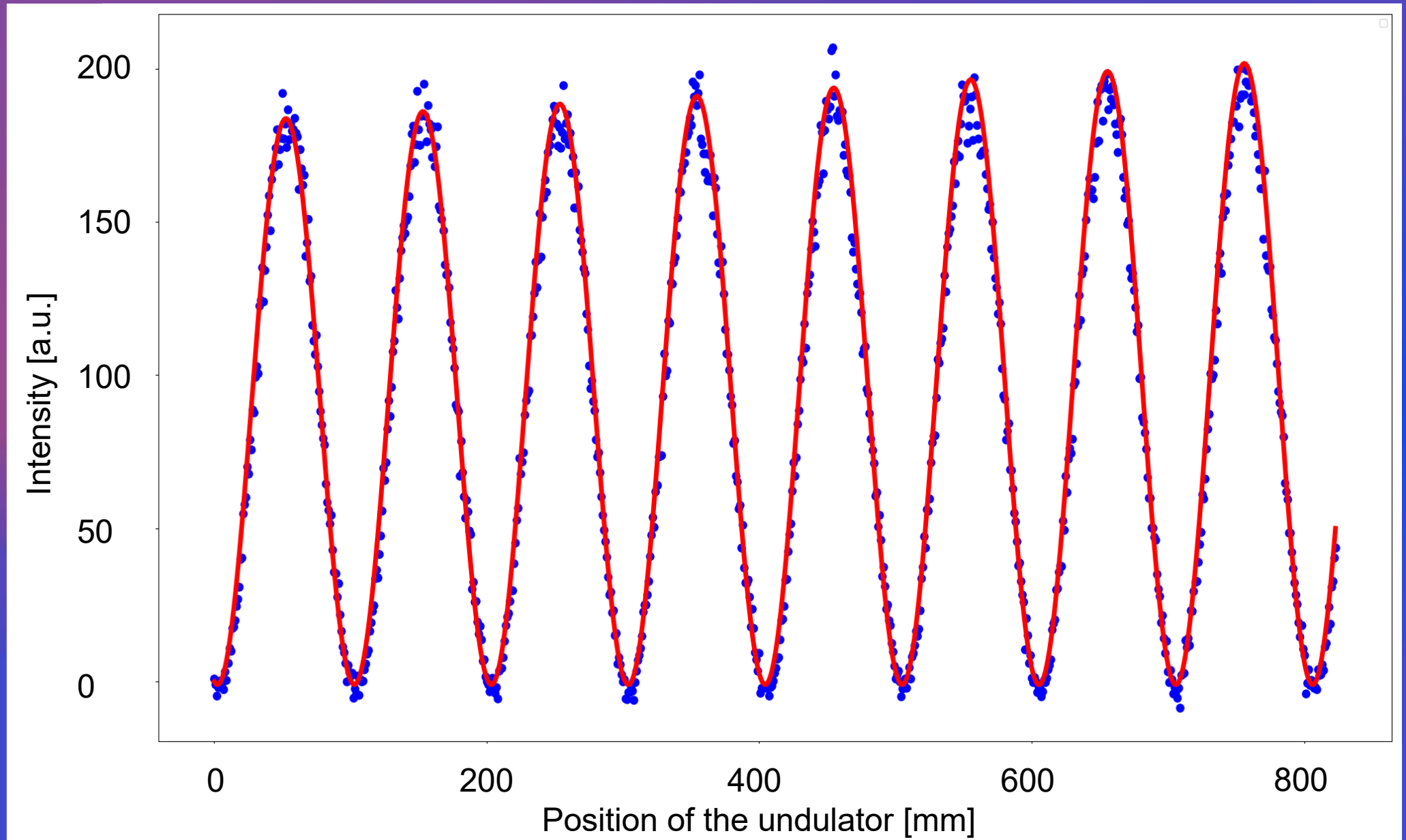
Simulated Undulator spectrum, (no Diffraction)



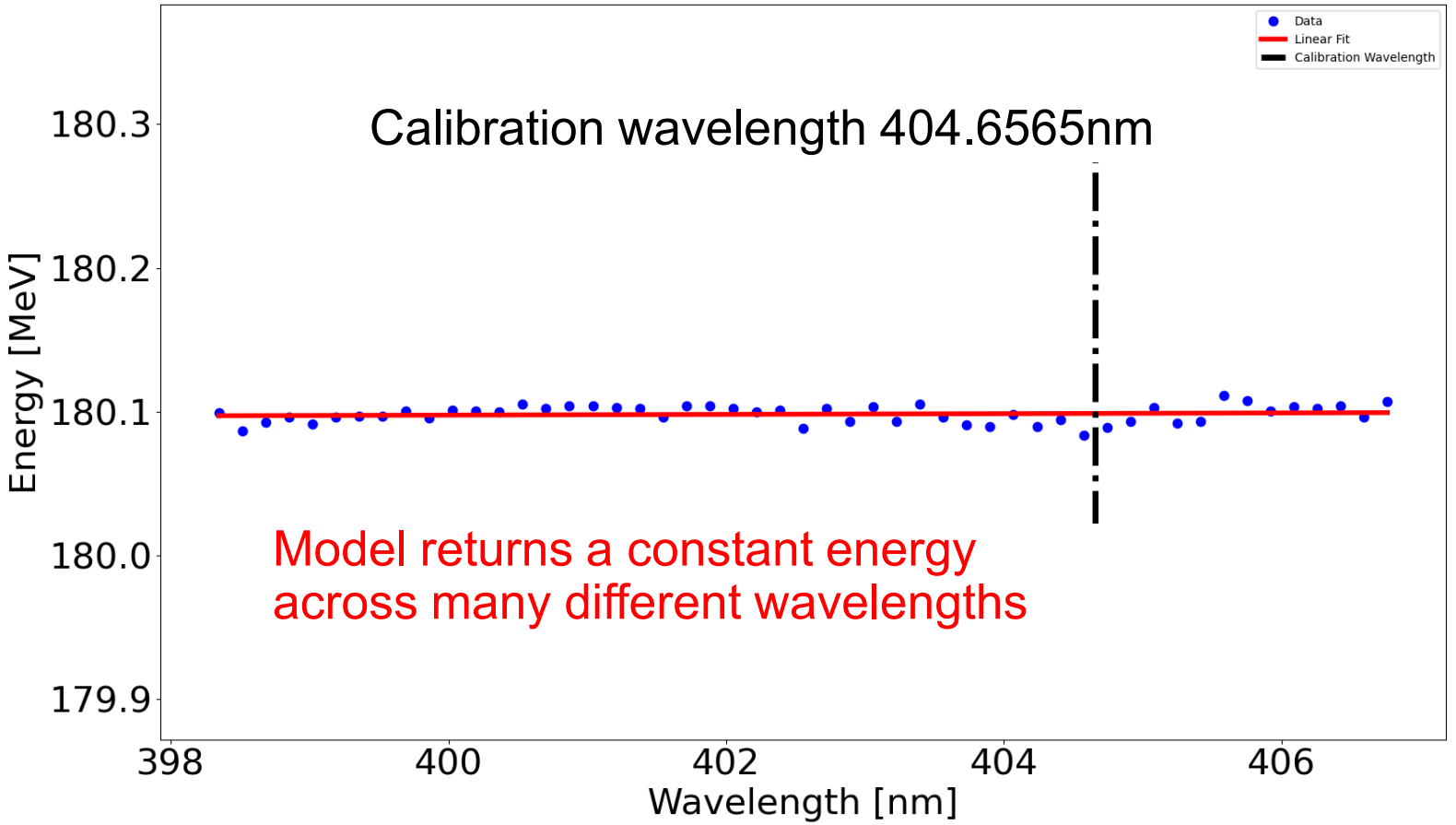
Example at 404 nm



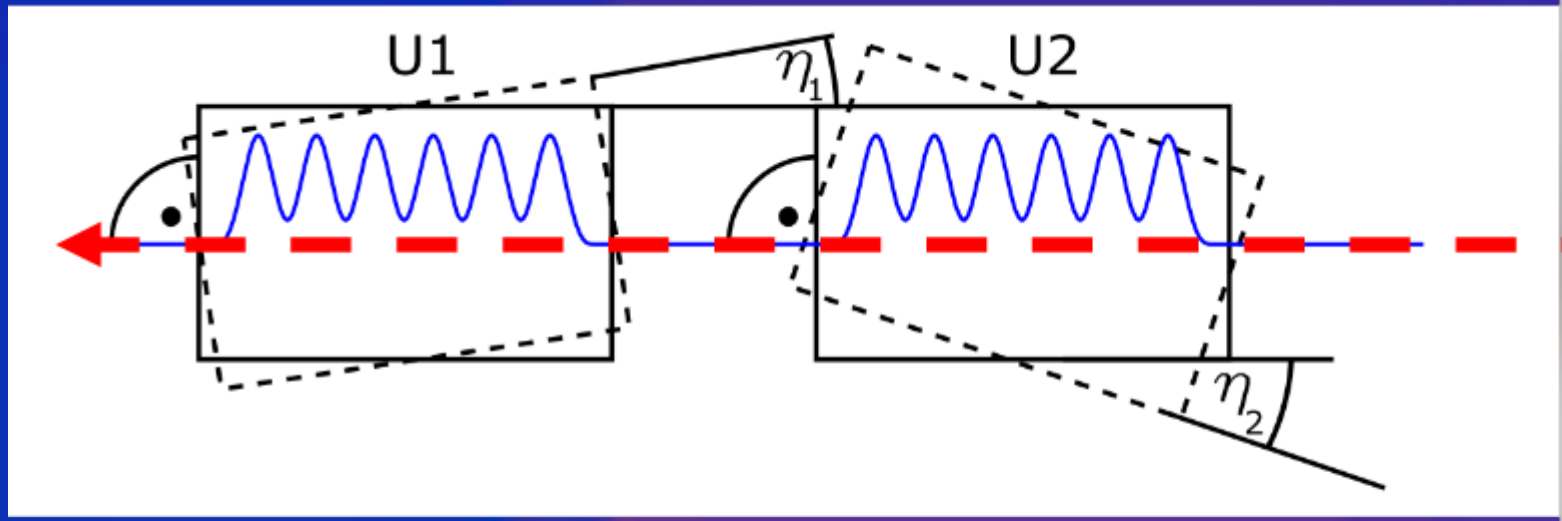
Intensity oscillation vs Position



Energy vs Wavelength



Alignment of the undulator pair with theodolites



Accuracy of the alignment with theodolites: 100µm

Sebastian Nizan - Own work
Theodolit - Model T2 manufactured by Wild, Heerbrug in the 1970th

Error to the energy due to uncertainty in the observation

Oscillation period depends on the angle θ:

$$\lambda_{Osc} = \lambda_{Osc}(\Theta)$$

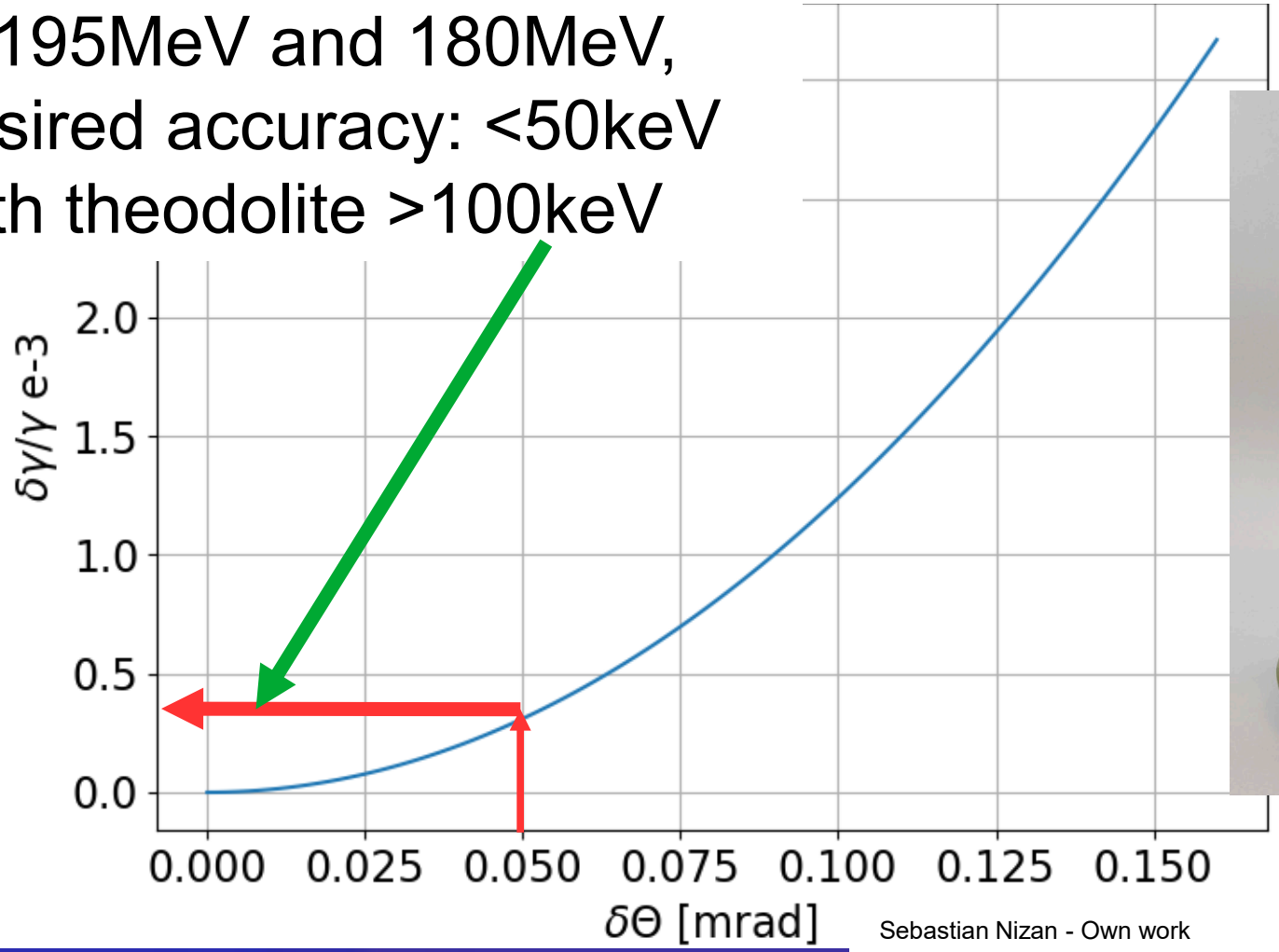
The uncertainty in the angle θ, (δθ) results in an error of the γ

$$\frac{\delta\gamma}{\gamma} = \frac{1}{2}\sqrt{\left(\frac{2\gamma^2\delta\Theta^2}{1+\gamma^2\delta\Theta^2}\right)^2}$$

Error to the energy due to uncertainty in the observation

With the Theodolite, δθ could be determined to about 0.05mrad:

At 195MeV and 180MeV,
Desired accuracy: <50keV
With theodolite >100keV



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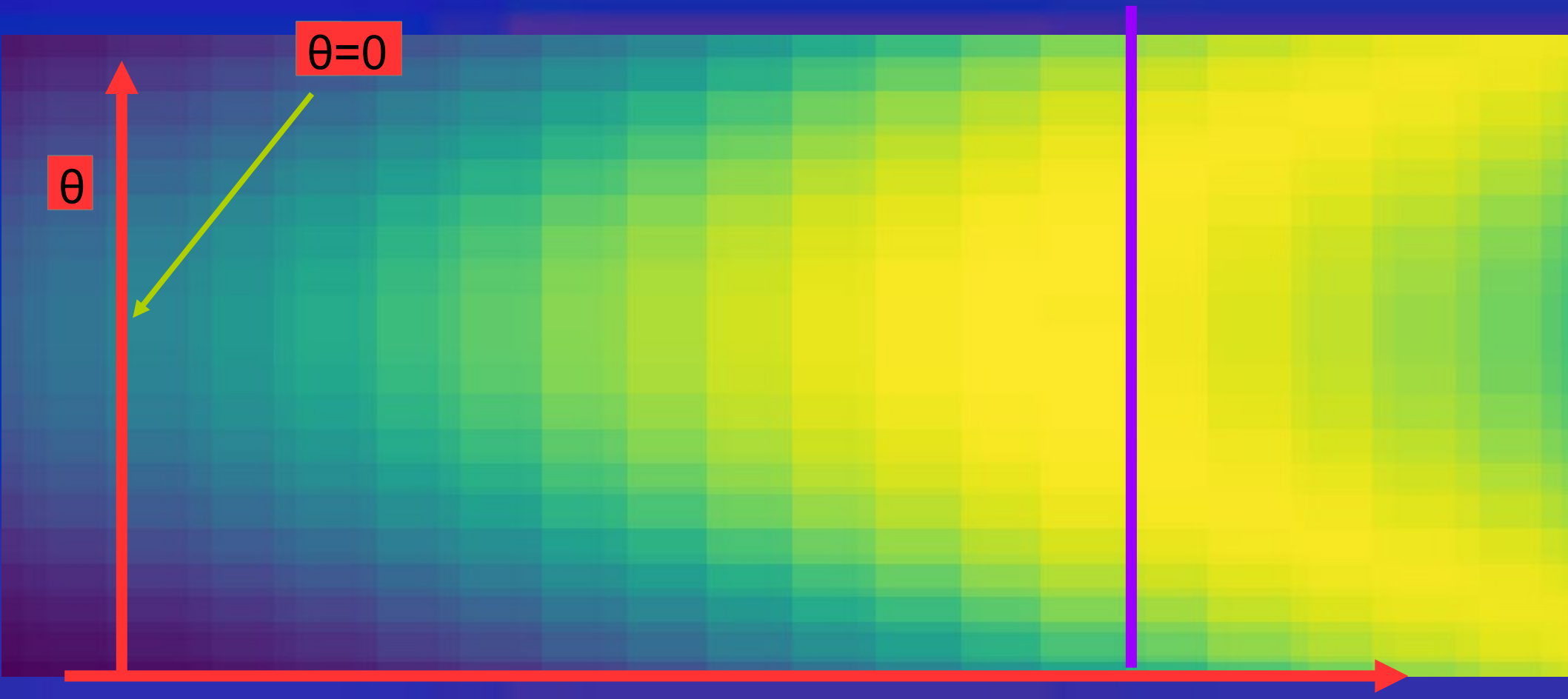
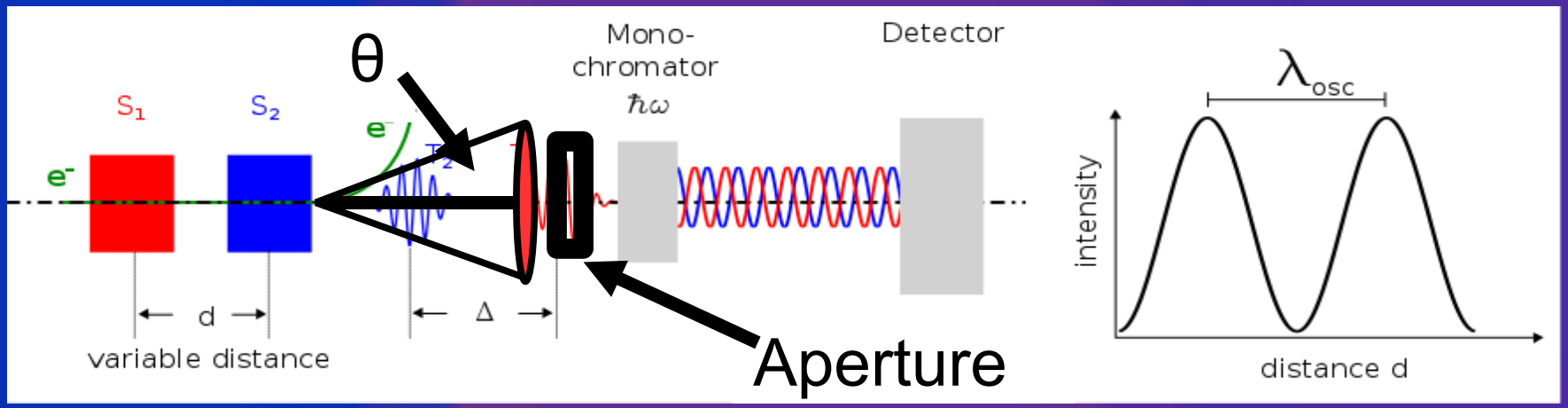
Simulated Undulator spectrum, (no Diffraction)



Method (including aperture)

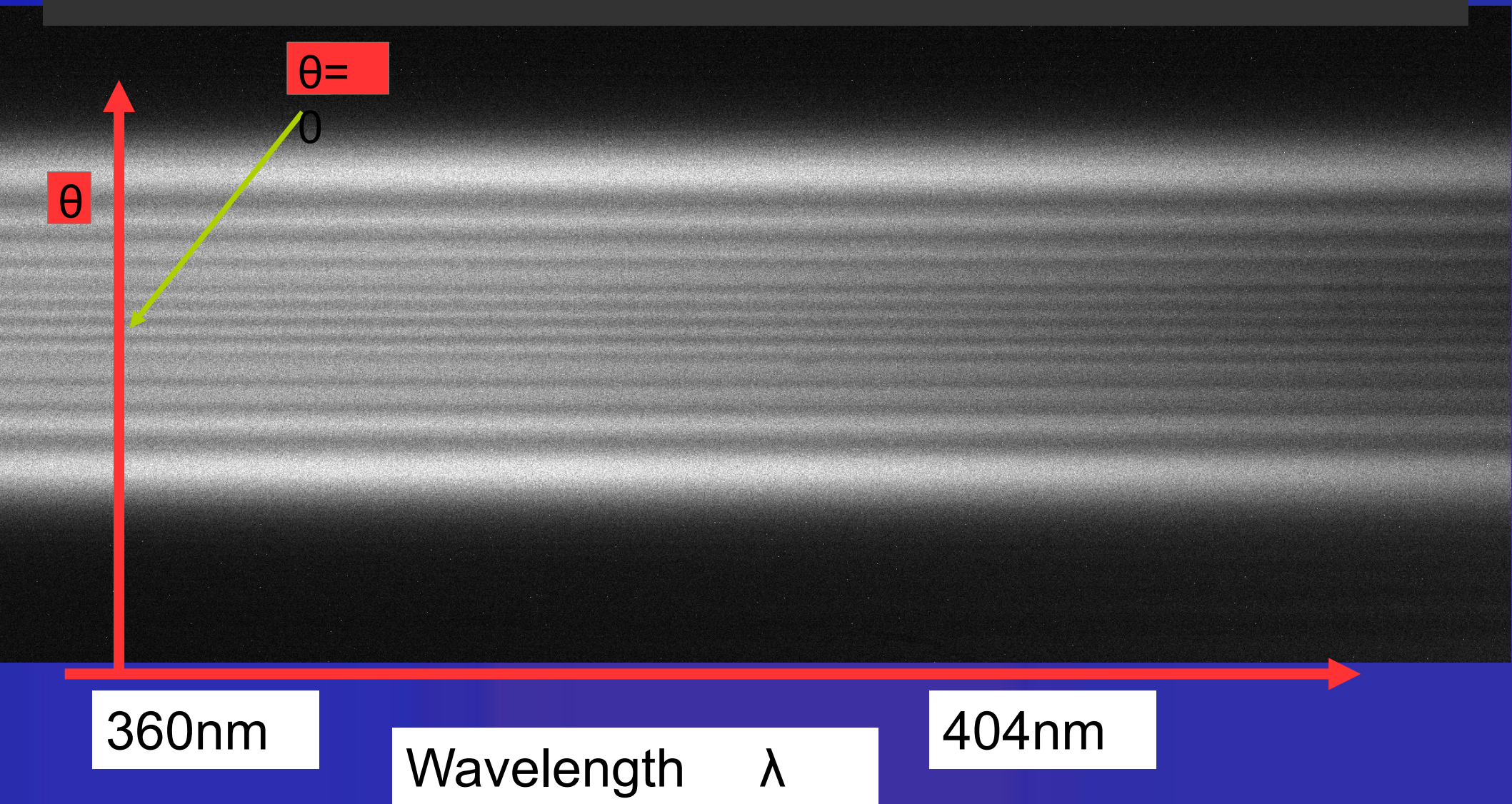
Undulators	Wave packets	Monochro-matic light	Light intensity of selected wavelength



$$\lambda_{osc} = 2\gamma^2 \lambda_L$$

$$\left.\begin{array}{l} \lambda_L \approx 400\text{nm} \\ \gamma \approx 381, \text{E=195MeV} \end{array}\right\} \lambda_{osc} \approx 116\text{mm}$$

Measured Undulator spectrum

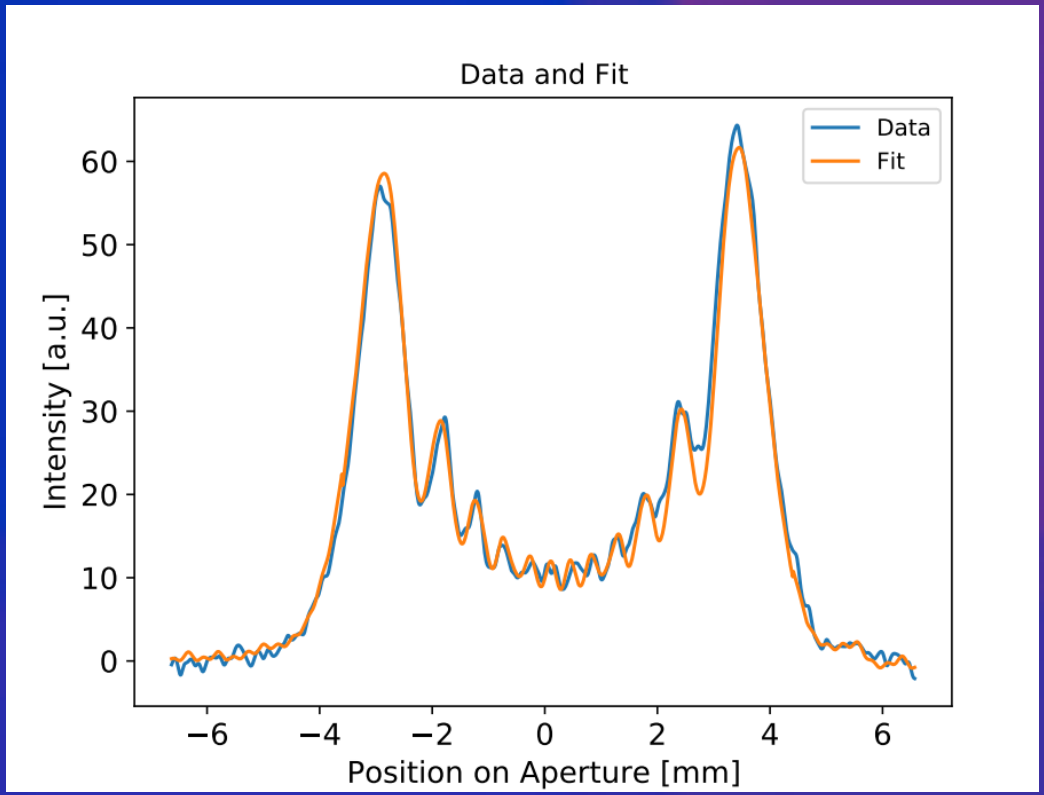


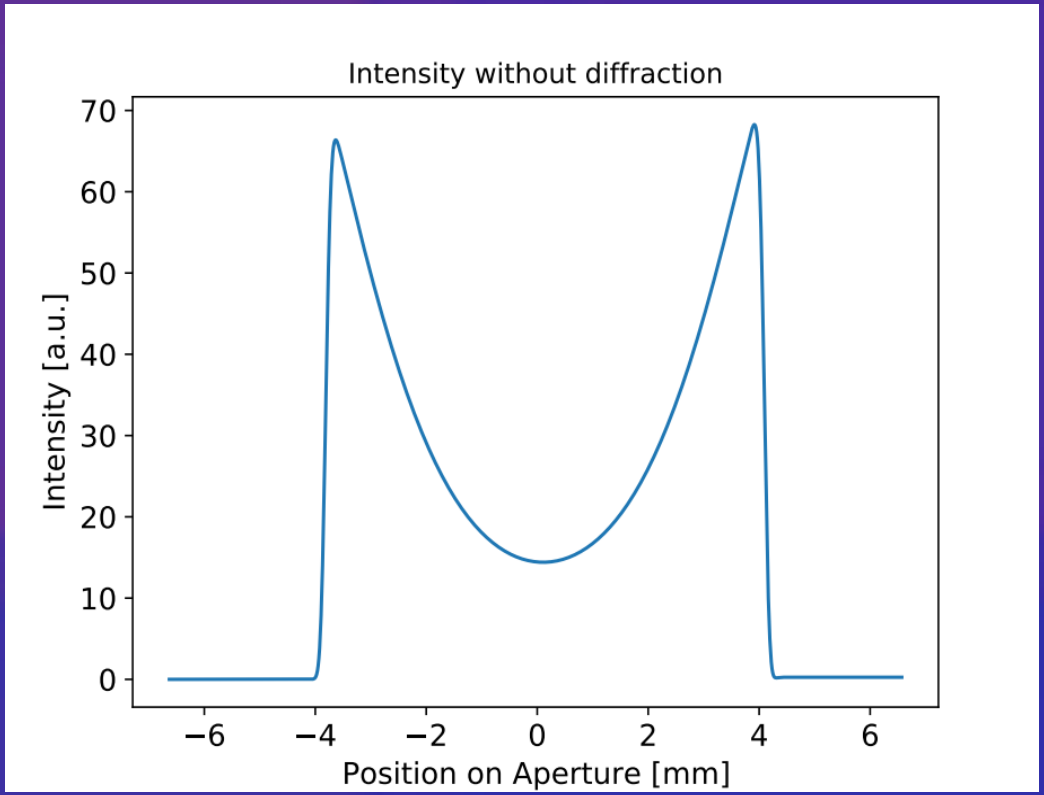
With Fresnel diffraction

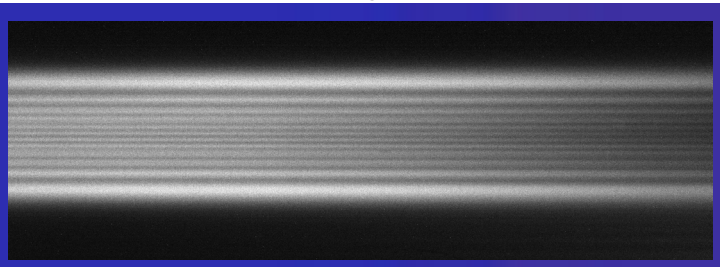
Example cut at 404 nm

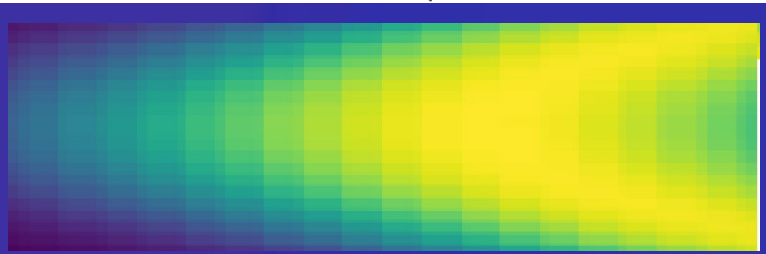
Fitted diffraction

No diffraction



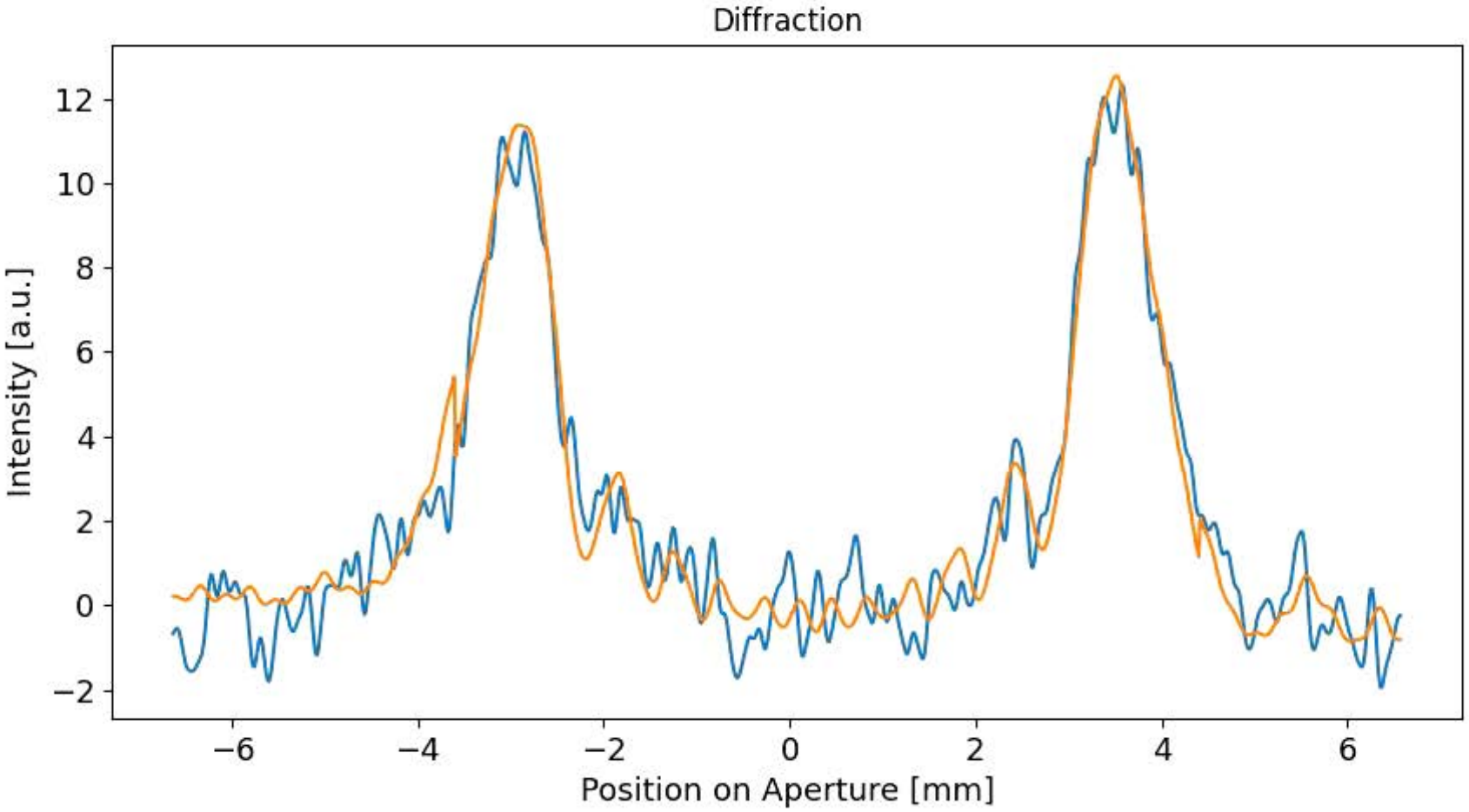






Example at 404 nm

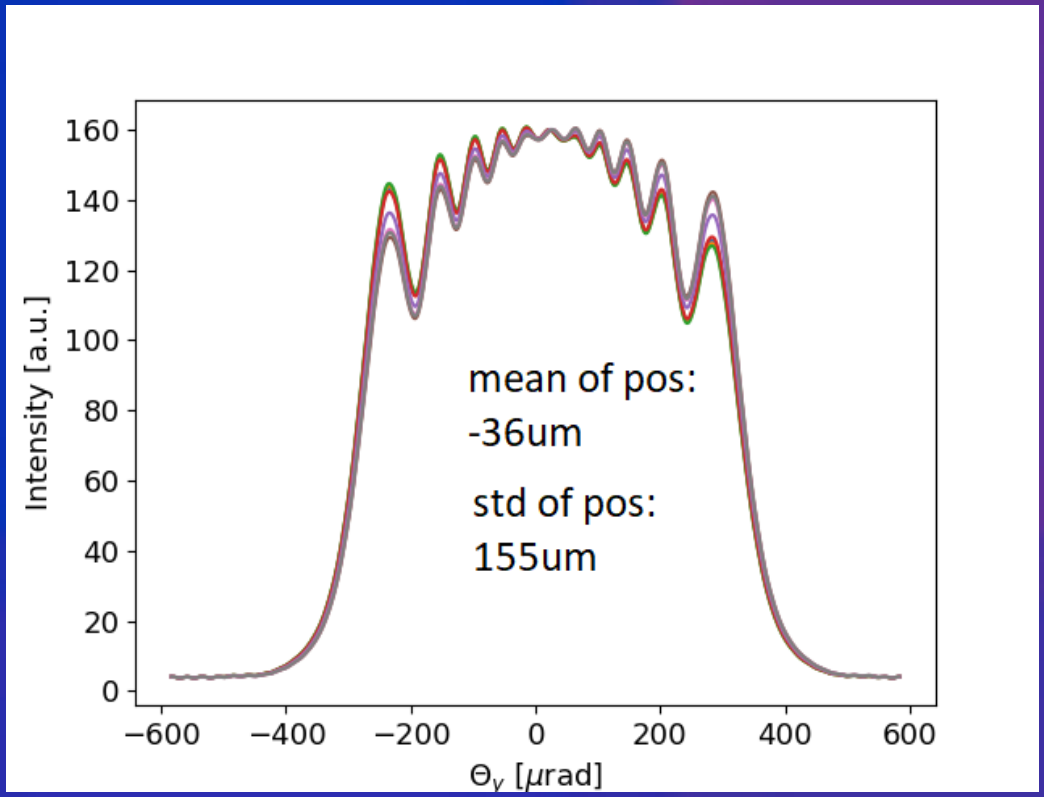
7 parameter fit
200 different wavelengths

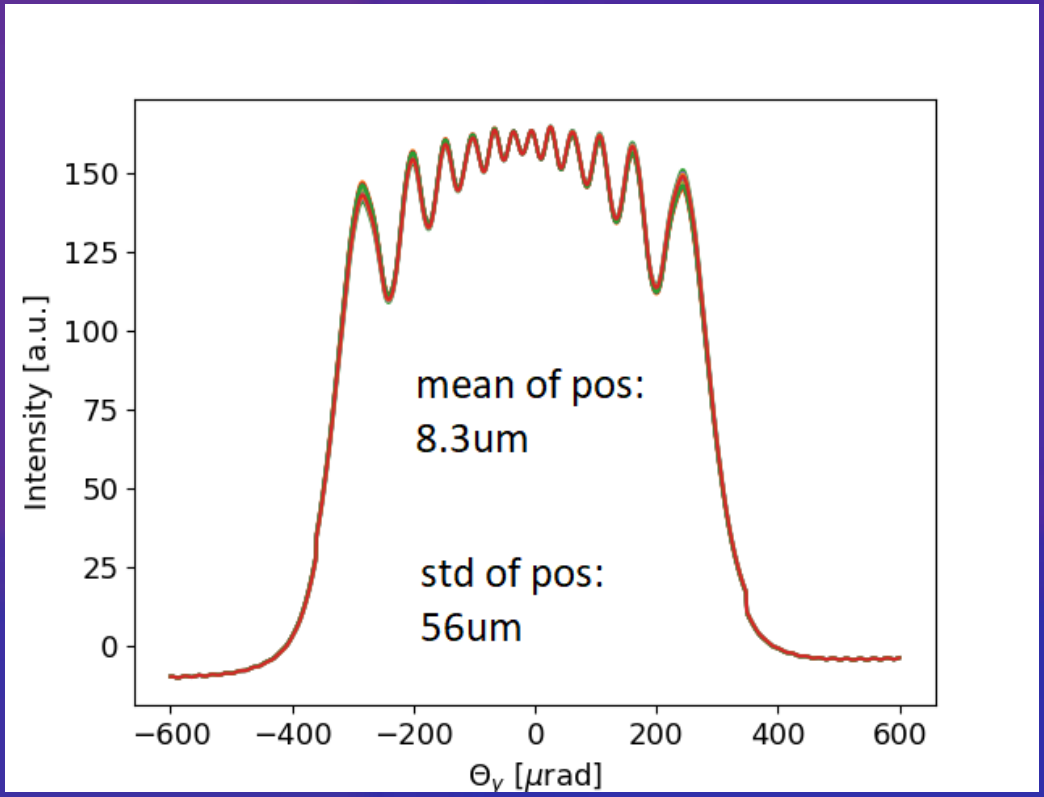


Improvements due to regulation

Without regulation

With regulation

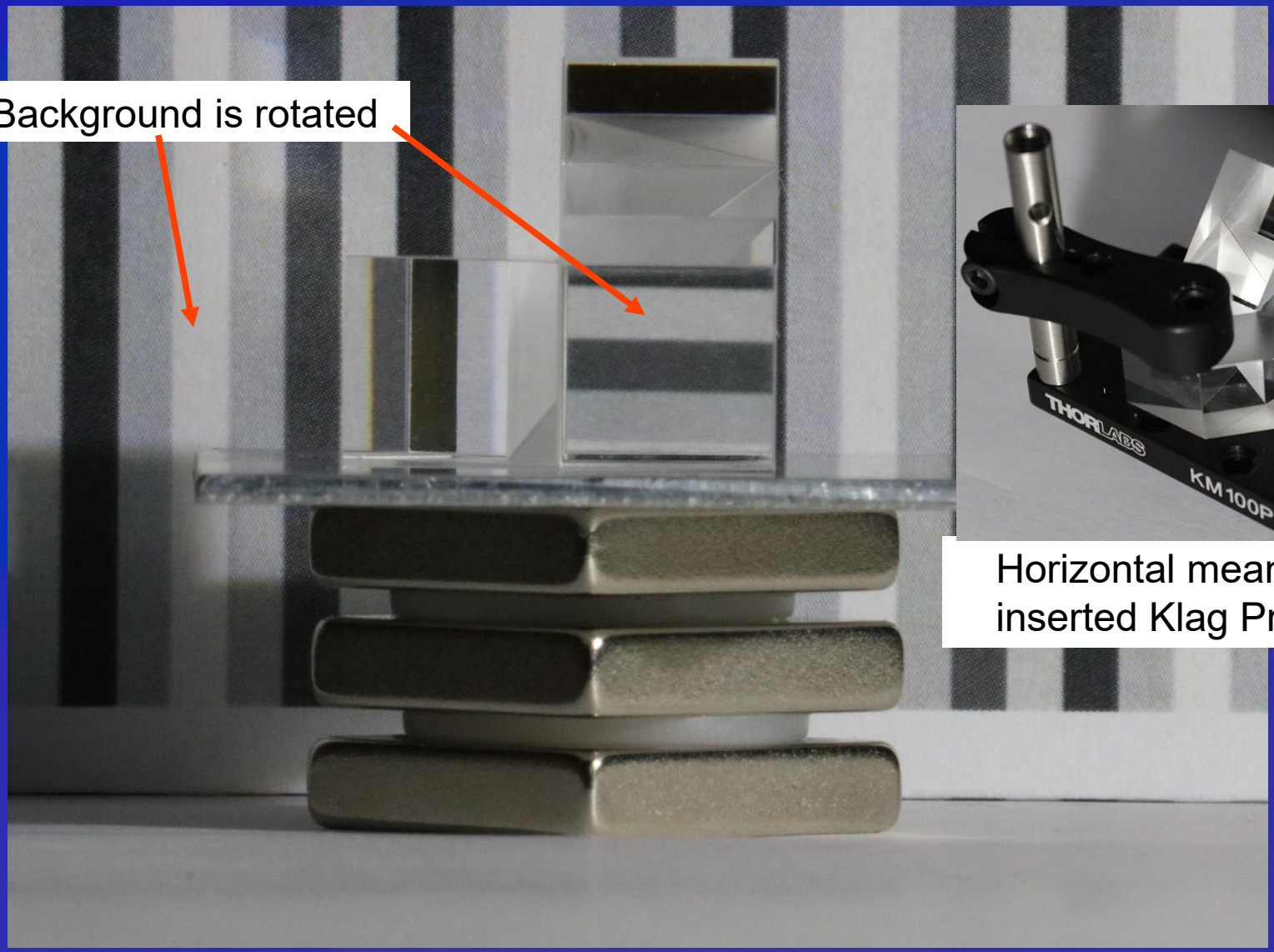




March 2020

June 2020

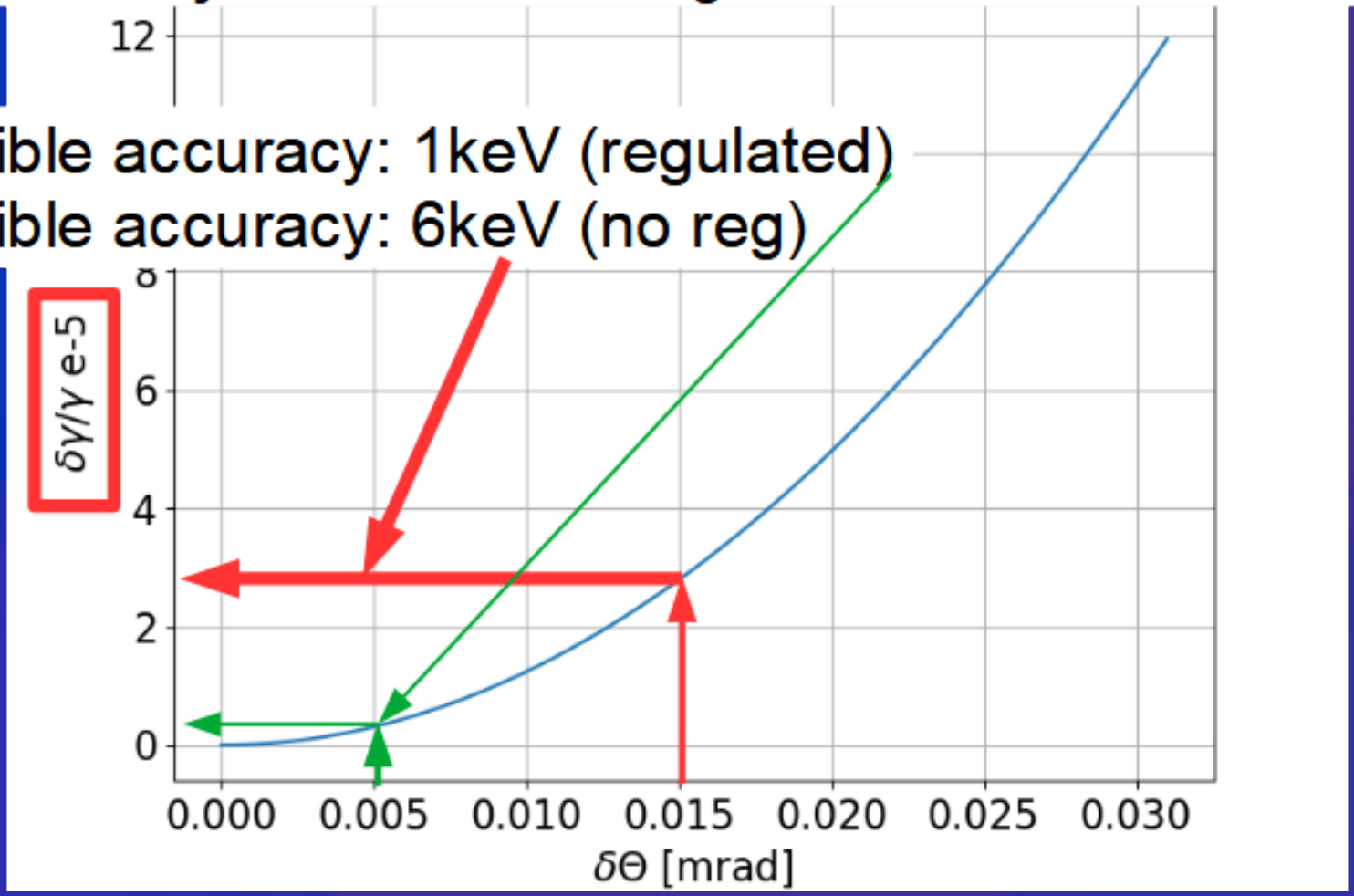
Exchanging horizontal and vertical direction



Horizontal means, with inserted Klag Prism

Reduced error to the energy

By using the diffraction pattern, the relative error is reduced by two orders of magnitude: E=195MeV



Status of the uncertainties

The uncertainties of the energy at 195MeV

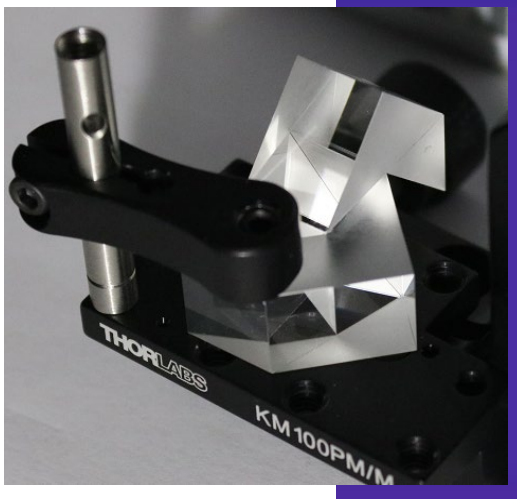
statistical: <0.9keV over 900x1000 pixels

systematics:

due to δθ by fitting,

only σ(hori/vert)**:** **Vertical: 1 keV**
Horizontal: 4 keV

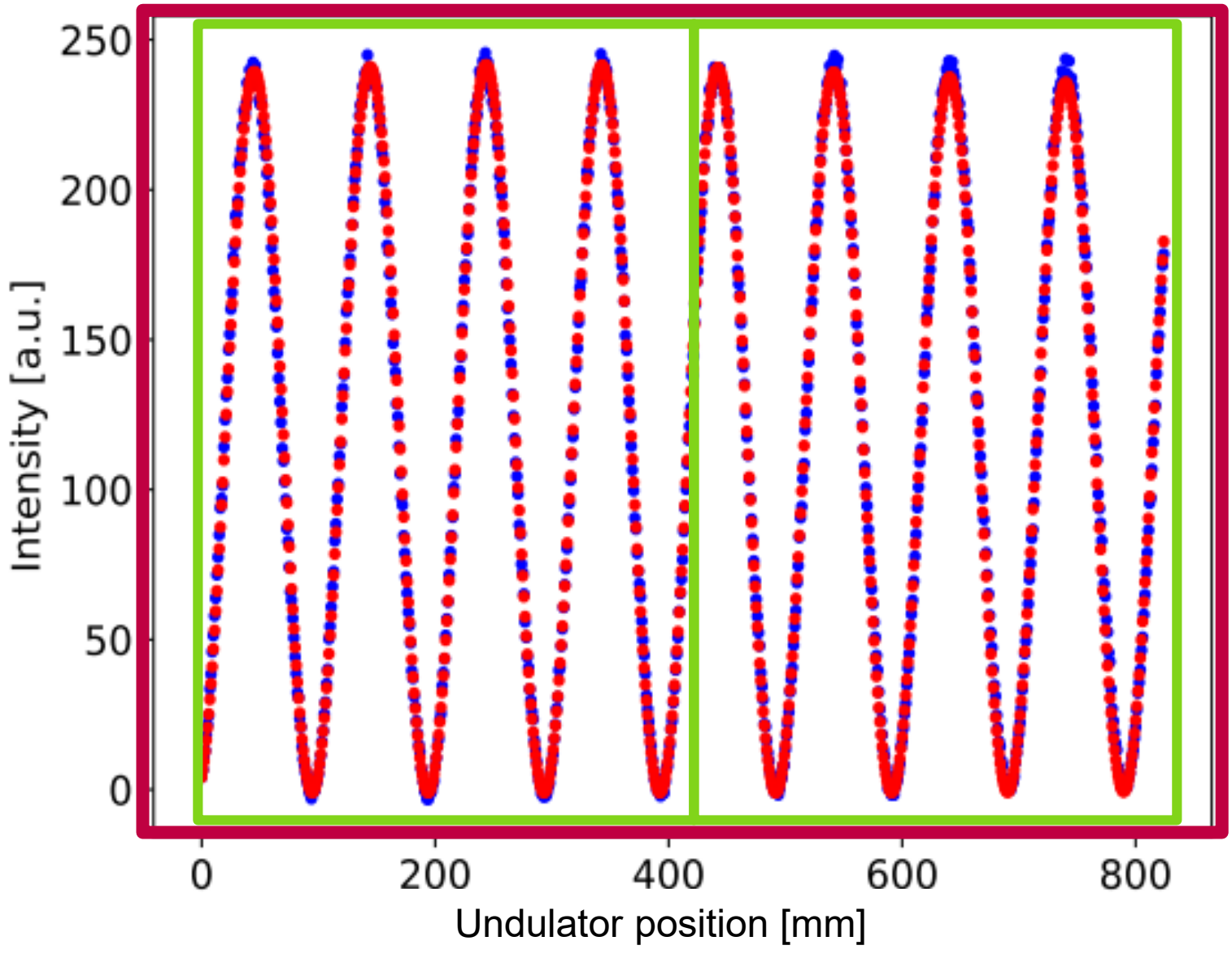
due to δλ : 2.2keV



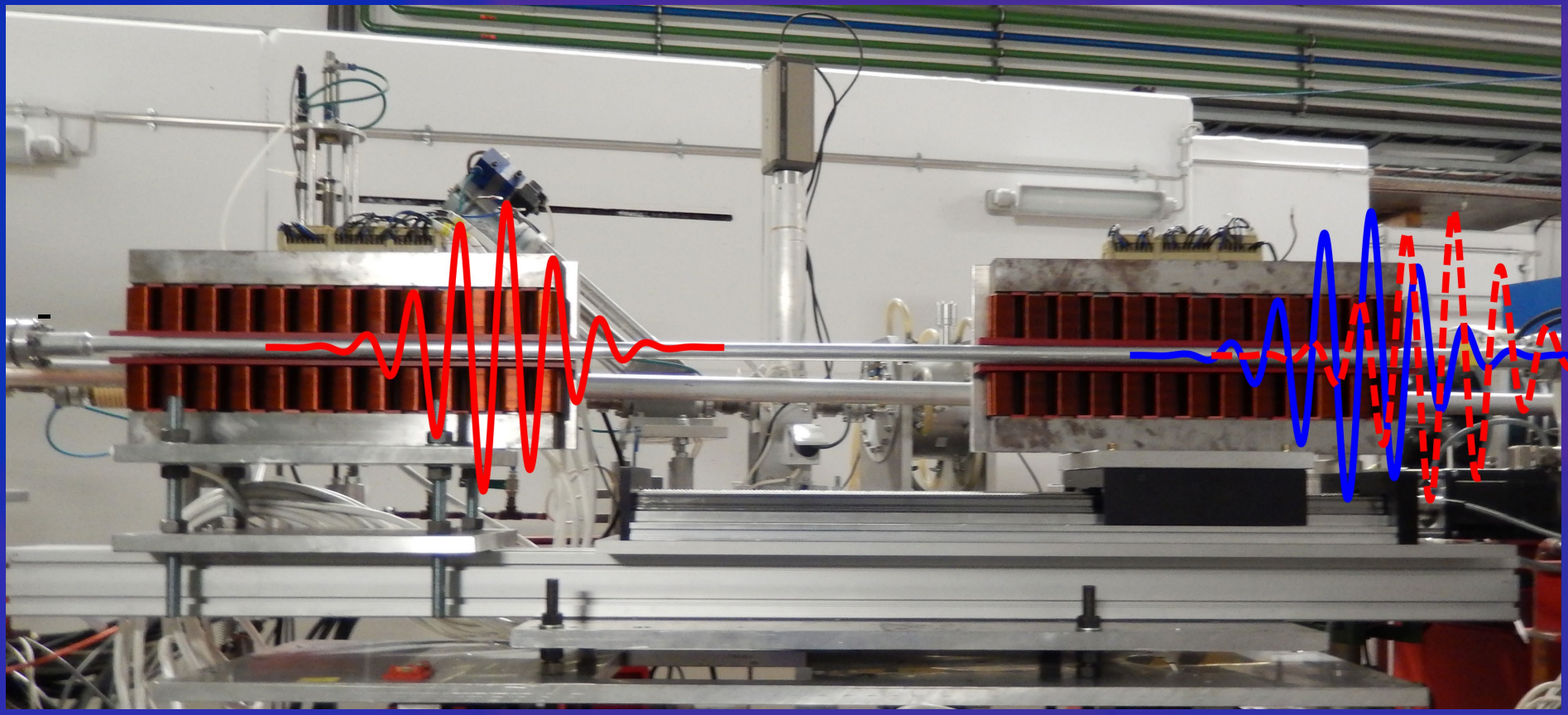
Horizontal means, with inserted Klag Prism

Fitting error (model uncertainty): 10-50keV

Systematic error of fit



Thank you for your attention



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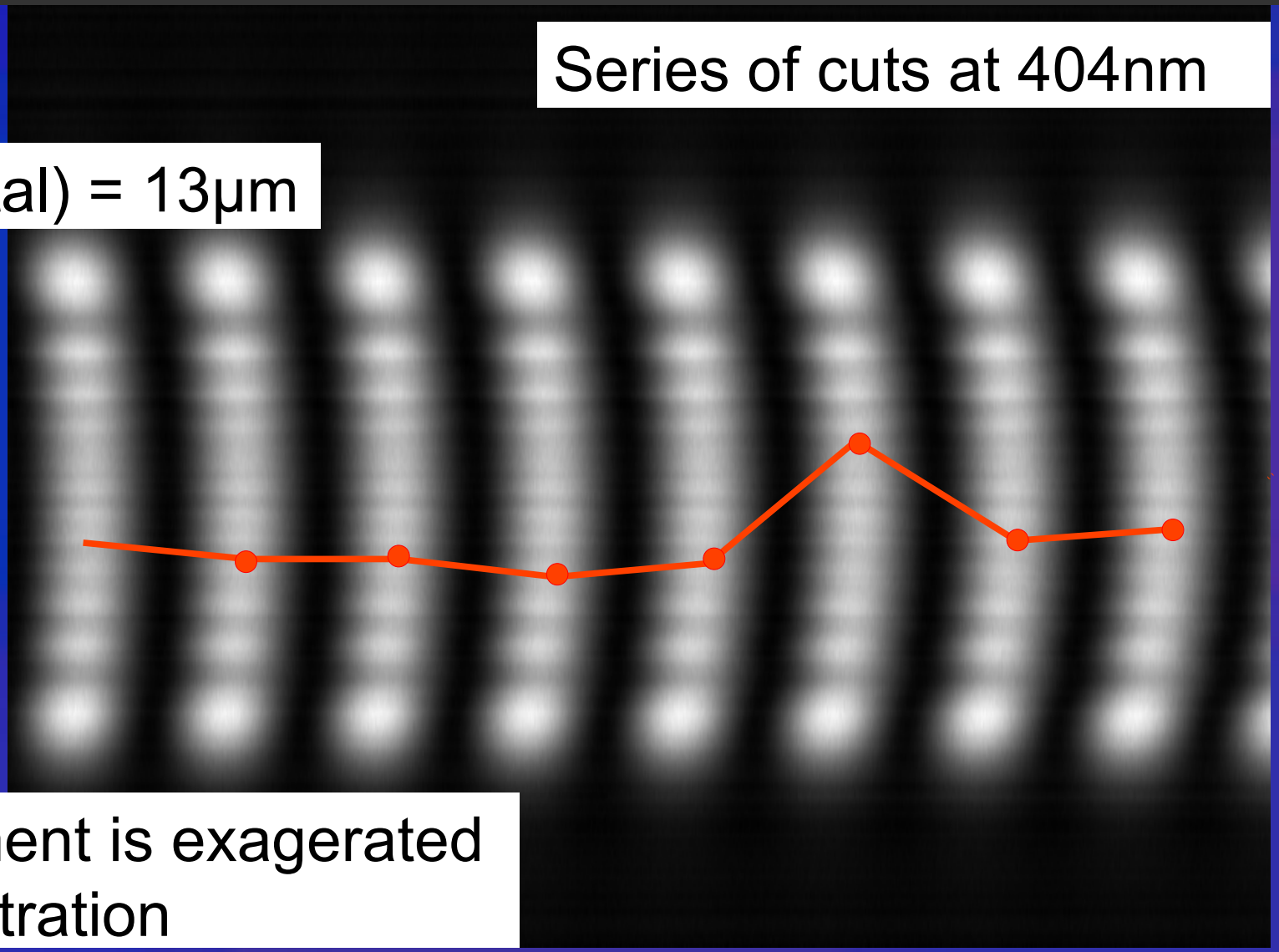
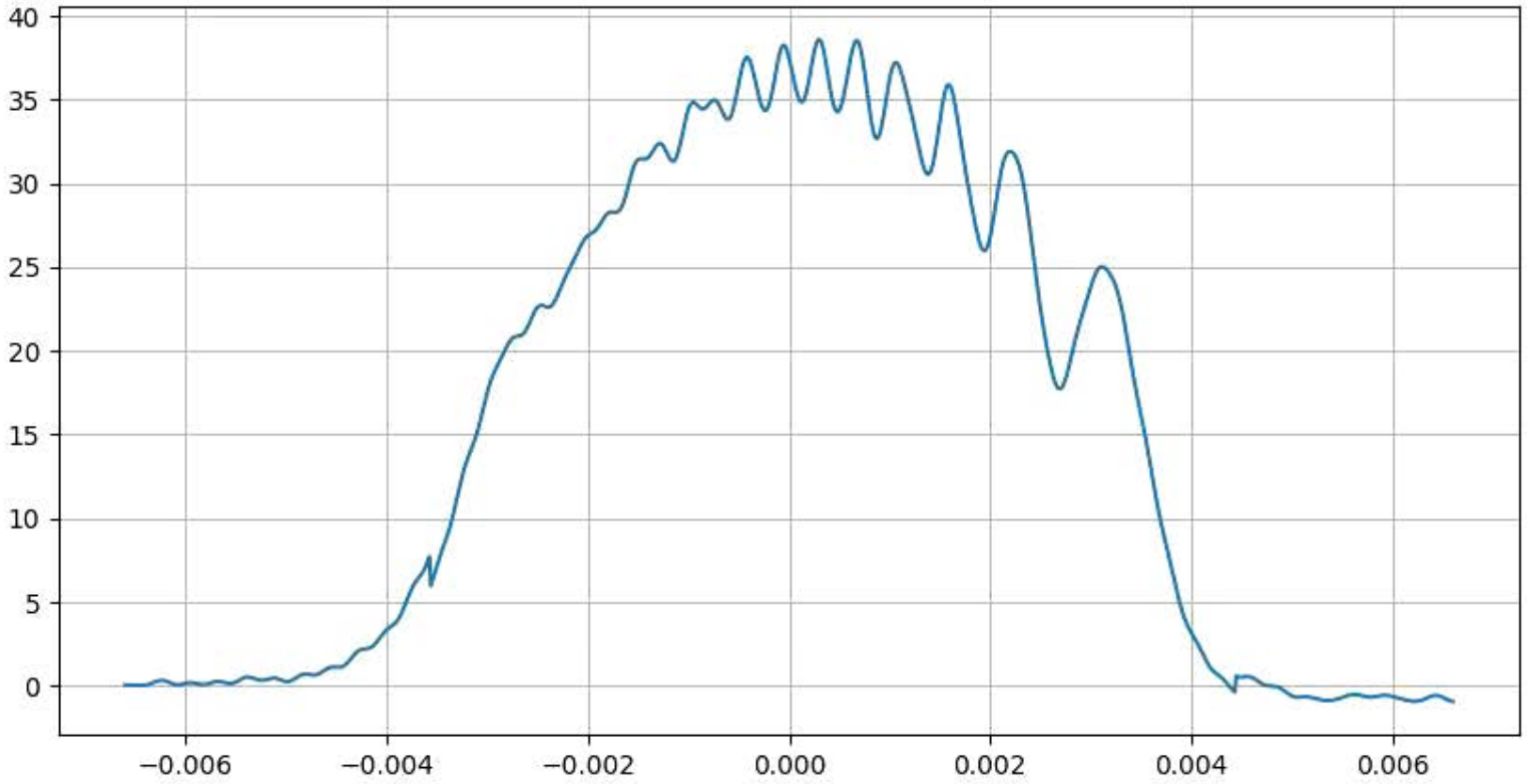
Uncertainty of the source for the horizontal dimension



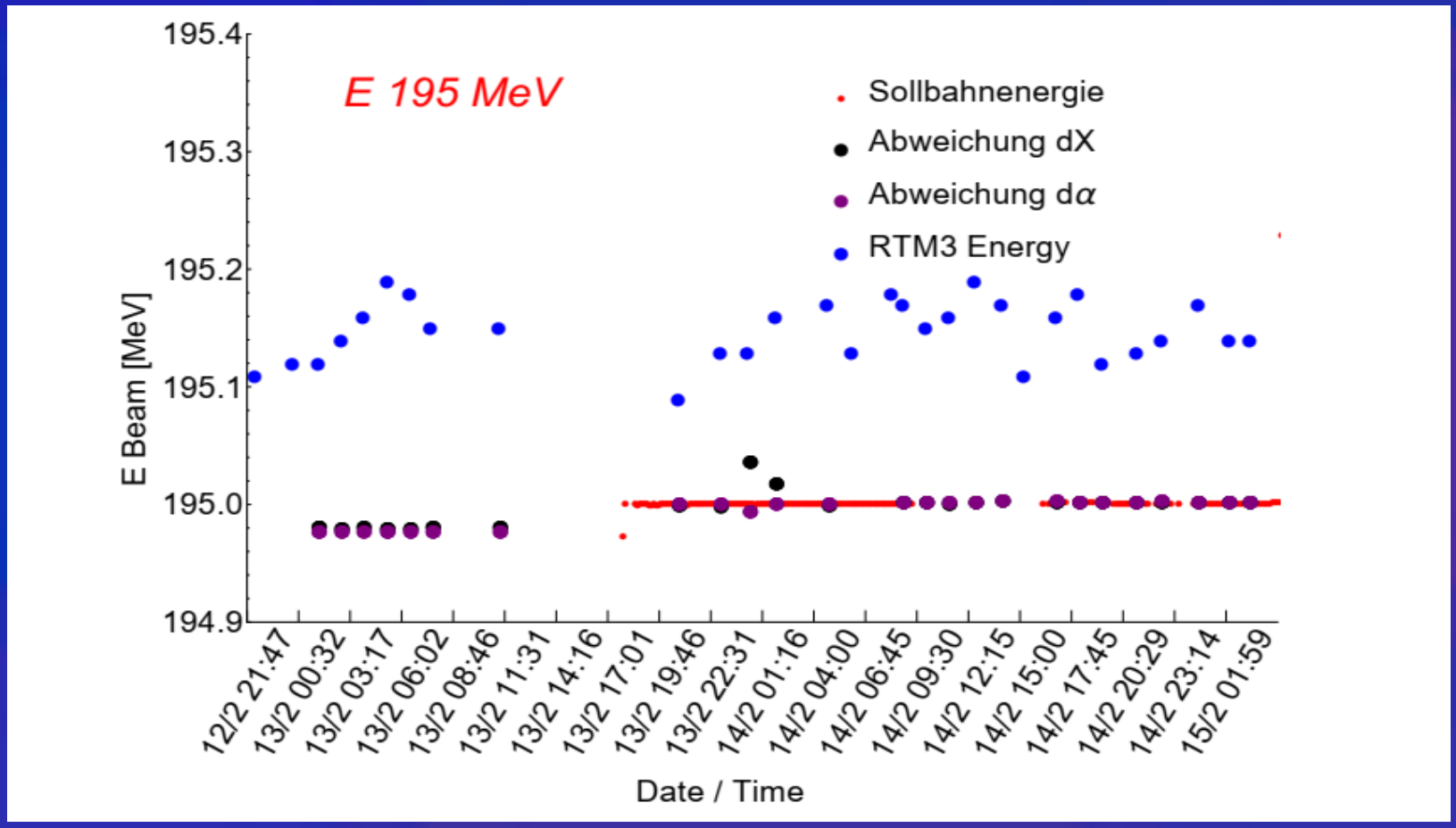
σ(horizontal) = 13μm

Movement is exagerated for illustration

Steering the electron beam against the aperture [-.02,.02]mrad

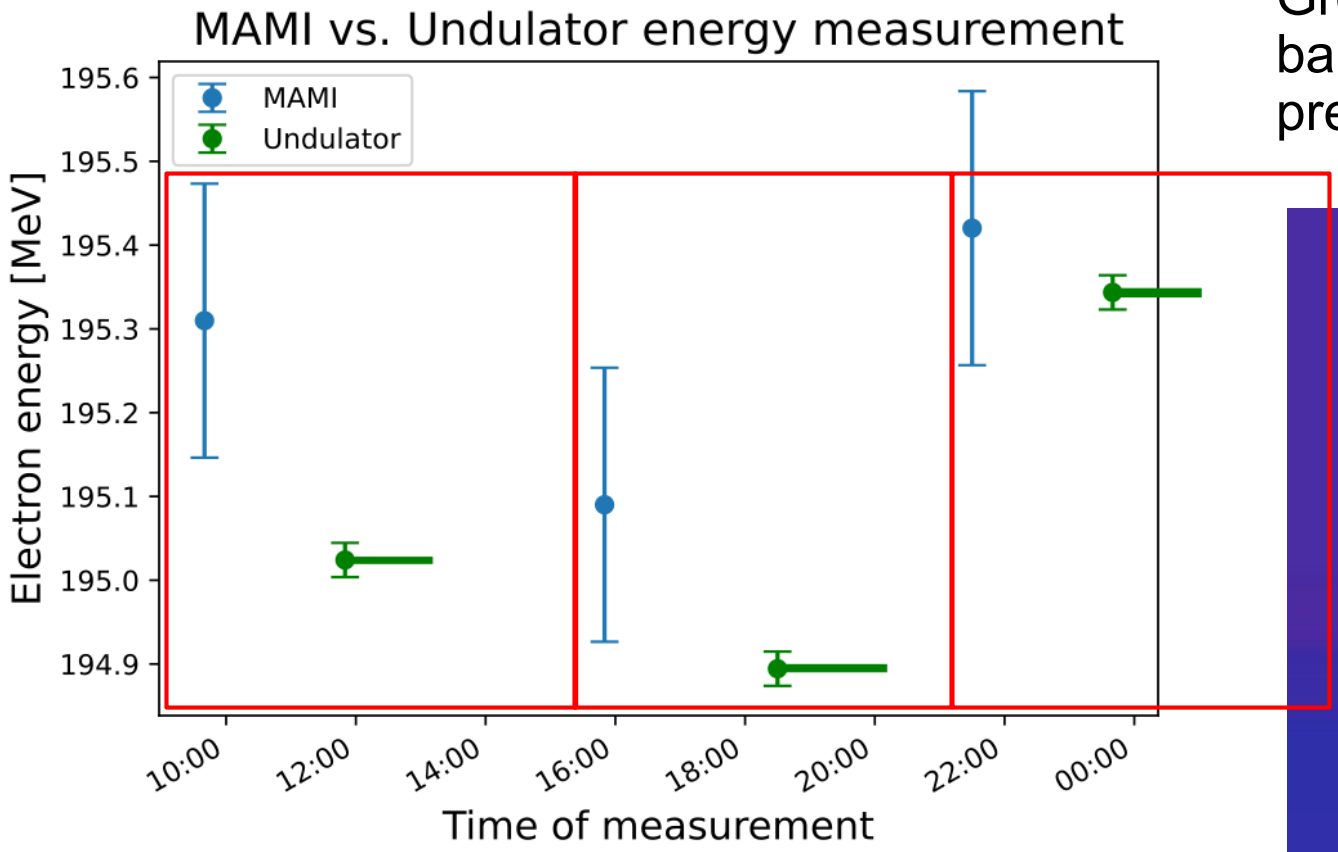


MAMI beam energy is very stable (if run several days)



Doktorarbeit Philipp Herrmann

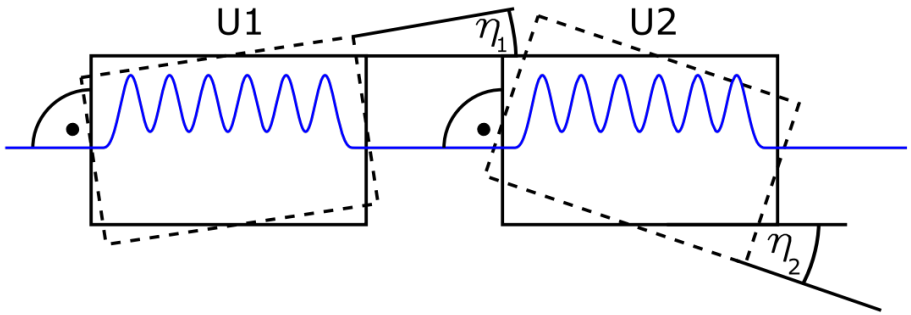
Comparison between MAMI and Undulator measurements

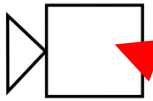


Green error bars are preliminary

Horizontal green bars show when the measurement ended

Insertion errors should <u>not</u> influence the oscillation period



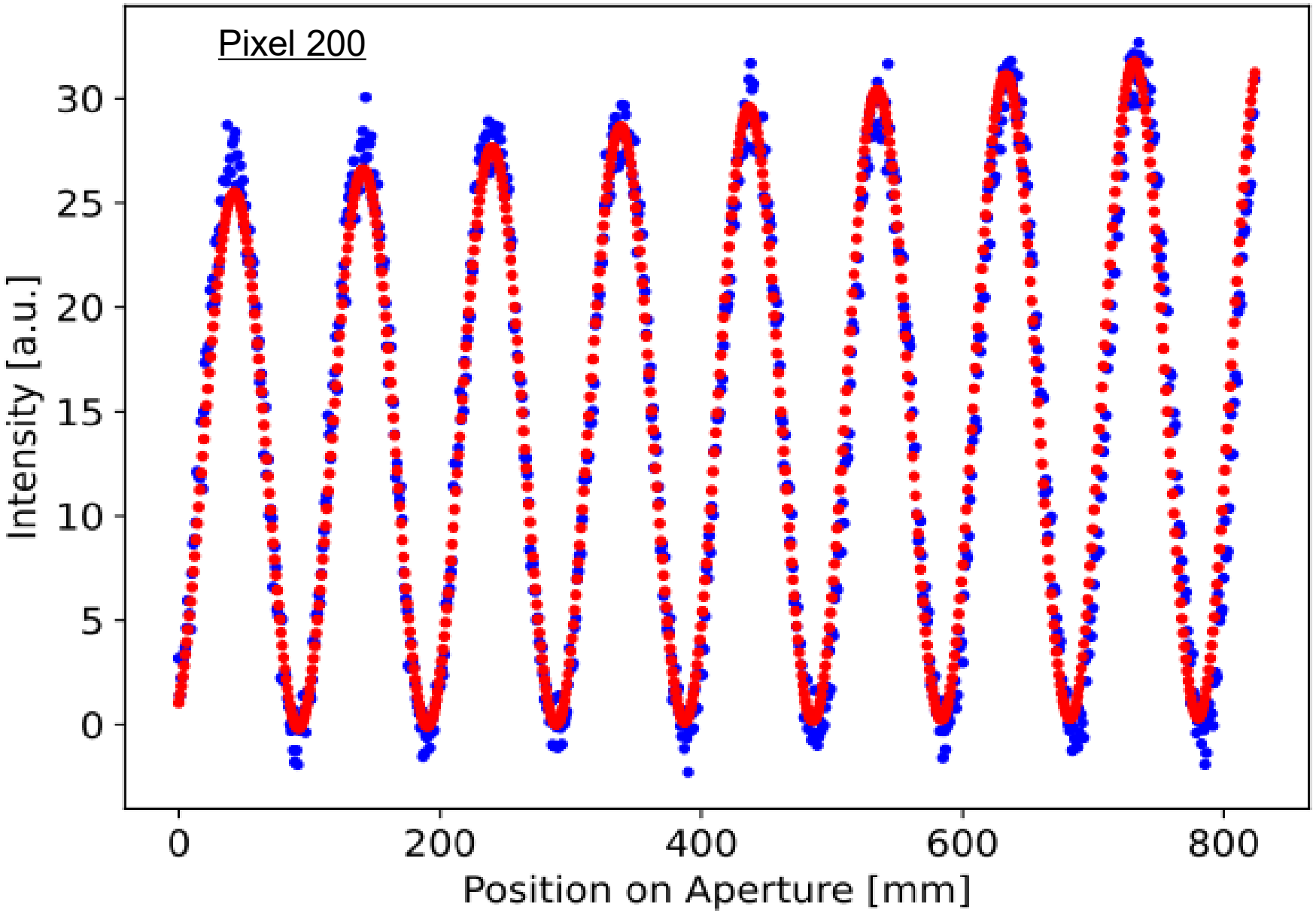


$$\lambda_{Urot} = \frac{\lambda_U}{cos(\eta)}$$

$$\lambda_R = \frac{\lambda_{Urot}}{2\gamma^2}\left(1 + \frac{K^2}{2}\right)$$

$$\lambda_R \neq \lambda_{osc}$$

Sebastian Nizan - Own work
Theodolit - Model T2 manufactured by Wild, Heerbrug in the 1970th


Pixel 200
Intensity [a.u.]
30
25
20
15
10
5
0
0
200
400
600
800
Position on Aperture [mm]

Status of the uncertainties

The uncertainties of the energy at 195MeV

statistical:

<0.9keV over 900x1000 pixels

systematics:

due to δθ by fitting, only σ(hori/vert):

Vertical: 1 eV
Horizontal: 30 eV

due to δθ, aperture pos:

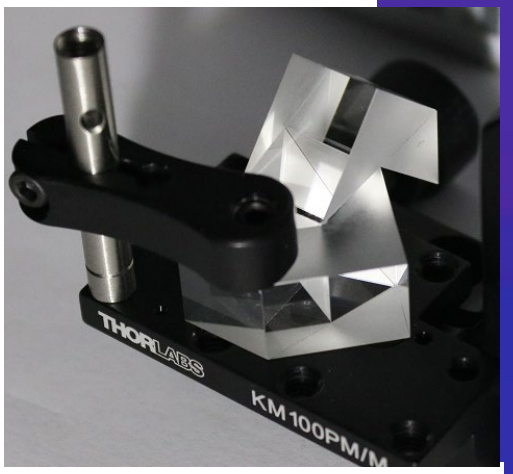
Vertical: 1.7 keV
Horizontal: 3.8 keV

due to δλ :

2.2keV

Fitting error (model uncertainty):

9keV



Horizontal means, with
inserted Klag Prism

Status of the uncertainties

The uncertainties of the energy at 195MeV

statistical:

<0.9keV over 900x1000 pixels

systematics:

due to δθ by fitting, only σ(hori/vert):

Vertical: 1 eV
Horizontal: 10 eV

due to δζ by fitting:

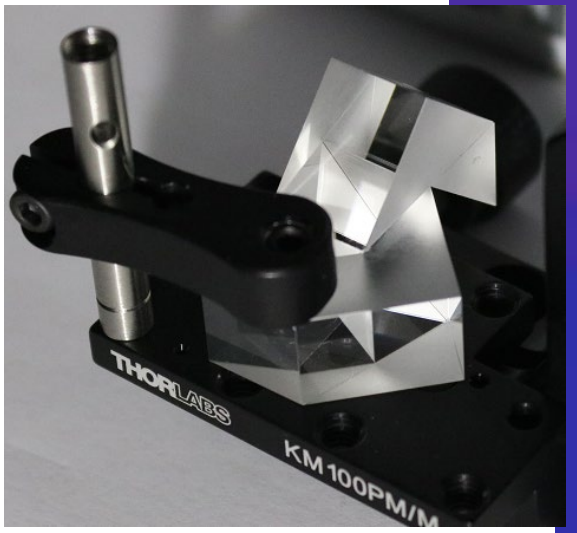
Vertical: .08 keV
Horizontal: 3.8 keV

due to δλ :

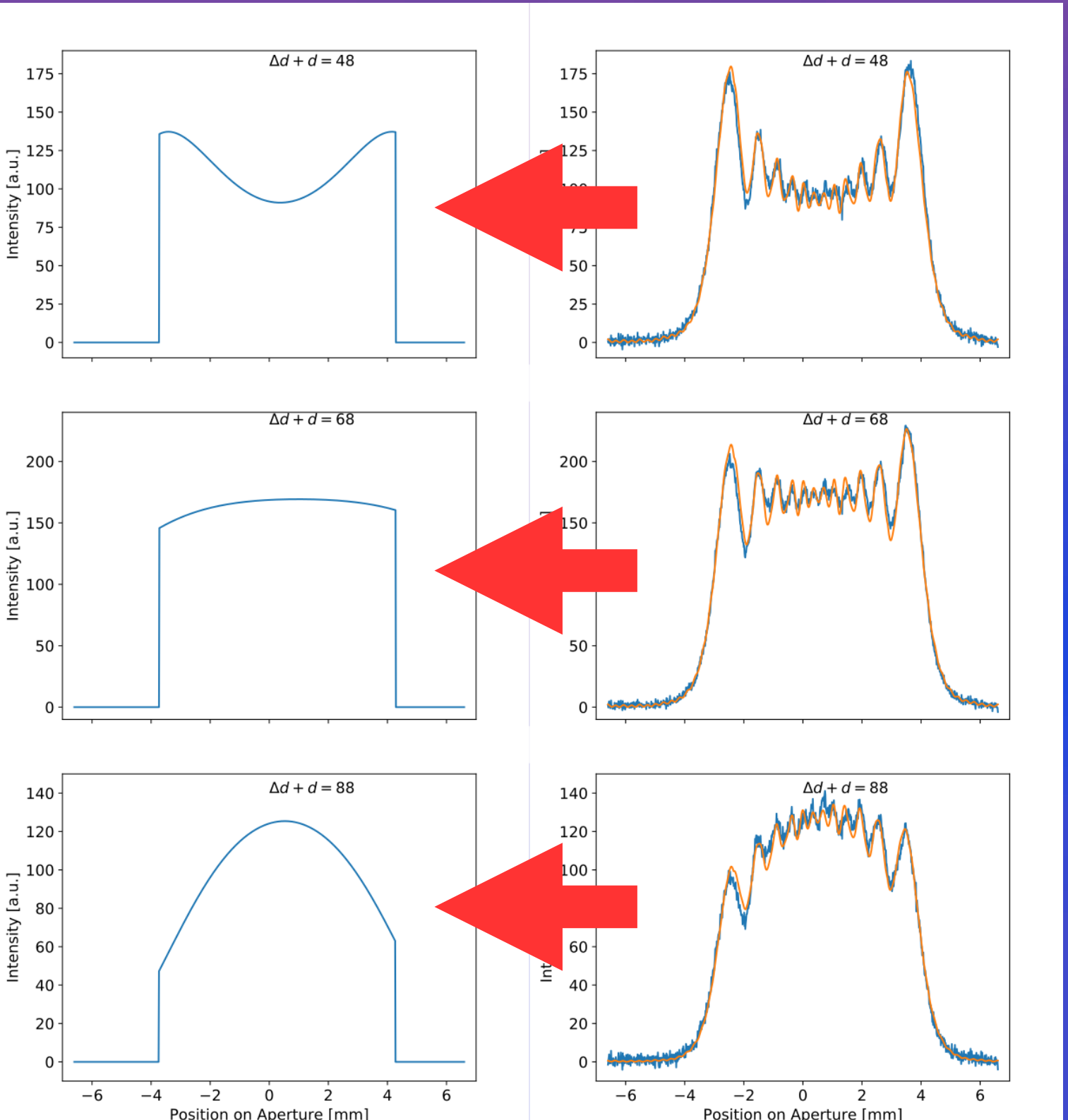
2.2keV

Fitting error (model uncertainty):

9keV



Horizontal means, with
inserted Klag Prism


Δd + d = 48
Intensity [a.u.]
Δd + d = 48
Δd + d = 68
Intensity [a.u.]
Δd + d = 68
Δd + d = 88
Intensity [a.u.]
Position on Aperture [mm]
Δd + d = 88
Position on Aperture [mm]

Thank you for you attention